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ALKALI SCRUBBING TEST FACILITY

PHASE 1 : PRELIMINARY ENGINEERING

A Report to

National Air Pollution Control Administration

Public Health Service
U. S. Department of Health, Education, and Welfare
Contract No. PH 22-68-67

May 1969

BECHTEL

FOREWORD

This report summarizes the first part ~~the results of Phases I and IA~~ of a program to develop an experimental facility to test sulfur dioxide scrubbing equipment and to prepare descriptions of the proposed tests. The program was conducted by Bechtel Corporation in accordance with Contract No. PH 22-68-67 with the National Air Pollution Control Administration, dated June 28, 1968, and amendments thereto.

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Section 1

INTRODUCTION

The National Air Pollution Control Administration (NAPCA) is conducting a comprehensive program to reduce sulfur oxides and particulate emissions from coal-fired power plants. As part of this extensive research and development effort, NAPCA has retained Bechtel to prepare a preliminary engineering design of the facility and to develop an experimental program to study the removal of sulfur oxides and particulates from flue gas by alkali injection and wet scrubbing.

While flue gas scrubbing with alkaline solutions is one of the oldest methods for removing SO_2 from flue gas, a satisfactory scrubbing system for this application has yet to be developed. Interest in alkaline scrubbing has continued because of its basic simplicity and comparatively low capital cost. Drawbacks of alkaline scrubbing are the need to dispose of large quantities of solid wastes and the tendency for accumulations of solids to plug the system.

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Large-scale experiments are needed to establish the most suitable scrubber system and the most effective and economical flue gas scrubbing method. The purpose of the work described in this report is to prepare a preliminary engineering design and cost estimate of a facility that can be used to test large-scale equipment under the variety of operational conditions that can be encountered in an actual plant. The basis of this design is the use of three parallel systems, each consisting of a different scrubber design, which will be integrated into the flue gas ductwork of an existing coal-fired boiler at Detroit Edison Company's St. Clair Power Station. Alkalinity will be supplied by injecting pulverized limestones or dolomites into the boiler. Heat from coal combustion will calcine these materials to produce calcium oxide or a combination of calcium oxide and magnesium oxide as the active agent for neutralization of sulfur oxides.

The total program is divided into three phases. This report is concerned only with Phases I and IA. NAPCA originally contracted with Bechtel to perform the following tasks in Phase I:

- Evaluate the site selected for the test facility
- Review and evaluate existing data pertinent to the chemistry and design of alkali flue gas scrubbing systems
- Develop a test program
- Develop preliminary design for the test facilities and their incorporation into the existing boiler system
- Prepare a budget cost estimate

An extension of Phase I, known as Phase IA, consists of the preparation of rough capital, operating, and restoration cost estimates for four alternative process schemes selected jointly by Bechtel and NAPCA, together with the development by Bechtel of capital, operating, and restoration cost estimates for one of these alternative schemes. The development of costs for the selected alternative was carried out to the same degree of accuracy and depth as for the base design of Phase I. The objective of the Phase IA work is to develop a preliminary design for a facility having a lower capital cost than that required by the Phase I design.

Phase II of the program will cover engineering, procurement, and construction of the test facility. This phase will also provide further details and specifications for the test program. Phase III will consist of conducting the test program.

Section 2

SUMMARY

Coal-burning boilers in power plants and industrial complexes are a significant source of air pollution, with particulates and sulfur oxides currently representing the most objectionable pollutants emitted. The National Air Pollution Control Administration (NAPCA) is sponsoring research and development work to find appropriate methods to remove these two pollutants.

One of the methods under study is alkali scrubbing of the flue gases. A three-phase program is planned to investigate various types of scrubbers to remove sulfur oxides and particulates with acceptable efficiency. Preliminary engineering of a test facility and conceptual development of a test program constitute the first phase of this effort. Phase II will be engineering and construction of the test facility and Phase III will be test program operation. This report represents the results of Bechtel's activities under Phase I.

The test facility will consist of three parallel scrubber systems, each with a different scrubber design and its own slurry handling system. Scrubbers will be of prototype size, each capable of treating approximately 100,000 acfm of flue gas. The slurry handling equipment will consist of a clarifier for basic liquid-solids separation and a vacuum-drum filter or centrifuge for further dewatering the solids before they are removed from the plant site.

2.1 PROCESS REVIEW

A detailed process review was made and covered the following topics:

- Status of Alkali Injection - Wet Scrubbing Process
- Furnace Reactions and Calcination
- Chemistry of SO_2 Absorption

The present status of this process indicates that SO_2 removal efficiency reaches 80 percent with approximately the stoichiometric amount of additive. Present commercial units include one at Union Electric's Meramec Station (140 Mw) and two plants for Kansas Power and Light Company (one 125-Mw unit and one 430-Mw unit). Two of the units have started up, but have not as yet reached design conditions due to operating problems.

The process consists of two steps—the injection of pulverized alkali into the boiler furnace and the alkali scrubbing of the flue gas to remove SO_2 and particulates. Within the boiler, a number of important reactions take place beside the combustion of fuel and sulfur. These consist of calcination of alkali solids, fixation of some of the sulfur oxides, and oxidation of some of the initial reaction products. Based on a review and evaluation of the literature, the following conclusions can be drawn:

- Injection of alkali solids near the fuel burner ports in the boiler furnace probably results in a hard burned lime with a slow dissolution rate.
- Injection ports should ideally be available in the furnace at several temperature zones (2200F and lower).
- Rate of heating of particles may affect lime dissolution rate. Shock heating, which could occur in a furnace, may affect this property.

Very limited data are available to confirm the above observations, and therefore it is recommended that small-scale tests be carried out to determine:

1. Residence time versus temperature for complete calcination
2. Effect of calcination temperature on lime reactivity (lime dissolution rate)
3. Effect of rate of calcining on lime reactivity
4. Effect of particle size as a parameter on 1, 2, and 3

The second step of the process involves the chemistry of SO_2 absorption. The following equations describe the chemistry in the scrubber circuit.

1. $SO_2 + H_2O \longrightarrow H_2SO_3$ (Absorption of SO_2)
2. $CaO + H_2O \longrightarrow Ca(OH)_2$ (Slaking of Lime)
3. $Ca(OH)_2 + H_2SO_3 \longrightarrow CaSO_3 + 2H_2O$ ($CaSO_3$ Formation)
4. $CaSO_3 + H_2SO_3 \longrightarrow Ca(HSO_3)_2$ (Bisulfite Formation)
5. $Ca(OH)_2 + Ca(HSO_3)_2 \longrightarrow 2CaSO_3$ and $2H_2O$ (Precipitation)
6. $CaSO_3 + 1/2O_2 \longrightarrow CaSO_4$ (Oxidation of SO_3 to SO_4)

In the limestone scrubbing process, which circulates a solution saturated with $CaSO_3$ the shift from monosulfite to bisulfite is considered to be the key mechanism responsible for absorbing SO_2 from the flue gas.

This means that the solution entering the top of the scrubber need not contain $Ca(OH)_2$ if there is the required stoichometric amount of $CaSO_3$ present. The pH of the liquor entering the absorber should be between 6 and 7. As the liquor passes down through the absorber, it absorbs SO_2, sulfite shifts to bisulfite, and the pH falls to between 5 and 6. Entering gas brings with it the alkali solids but these do not have time to dissolve within the scrubber. In the liquor circuit outside the scrubber, solution occurs and $Ca(OH)_2$ forms, and then reacts with the bisulfite to precipitate $CaSO_3$.

If a saturated solution of $CaSO_3$ is used, the solubility of $CaSO_3$ determines the circulation rate required for a given SO_2 concentration in the flue gas. If the circulation rate is too large, a slurry may be used. The limited data available on $CaSO_3$ solubility required that solubility data on the $CaSO_3$ - $Ca(HSO_3)_2$ - $CaSO_4$ - H_2O system be obtained to establish accurately the process requirements.

The chemistry just described for lime also applies to MgO in dolomite. However, some significant differences in system operation would occur due to differences in solubilities of $Mg(OH)_2$ and $MgSO_3$. The different hydration rate of MgO may also be important.

In the design of the alkali scrubbing process, gas-liquid equilibrium data are required. The equilibrium between SO_2 and aqueous solutions based on calcium and magnesium have been investigated by a number of workers. Unfortunately, most of the data available is for conditions other than those encountered in alkali scrubbing. The data of Kuzminykh and Babushkina covers the lower SO_2 partial pressure values. Their measurements are for P_{SO_2} in the range of 20 to 300 mm Hg. Since the P_{SO_2} in flue gas is approximately 1 mm Hg, these data are for a higher partial pressure range than that needed for the alkali scrubber design.

Pinaev has measured P_{SO_2} over aqueous $Mg(HSO_3)$ solutions and obtained data over the range of 0.03 to 0.15 mm Hg at temperatures of 30 to 60C. The effect of $MgSO_4$ upon P_{SO_2} was determined: as $MgSO_4$ concentration increases, P_{SO_2} increases. Pinaev's findings are useful for inferring what may occur in the calcium system.

Sufficient gas-liquid phase equilibrium data for the gas-phase SO_2 concentration of interest are not available. These data need to be developed in order to evaluate scrubber performance in the test facility and for design of full-scale systems. In obtaining this data, specific attention should be given to effects of sulfite and sulfate concentration upon the equilibrium curve.

Table 5 - 2 summarizes the information gathered in the process review and indicates data required to be determined in the test program or measured in a laboratory.

2.2 SCRUBBER EVALUATION

A number of commercial scrubbers exist for the removal of SO_2 and particulates from flue gas. In order to select scrubbers that could satisfy the requirements of the alkali injection-wet scrubbing process, performance and design information was obtained from published studies, from meetings with scrubber manufacturers, and from observation of scrubbers operating at conditions similar to those of the test program. The performance of flooded-bed scrubbers installed at Union Electric Company's Meramec Plant by Combustion Engineering was investigated in detail. Meetings with Dominion Tar and Chemical Company provided an opportunity to observe the operation of large-scale turbulent-contact and venturi scrubbers. An observation of a large impingement-plate scrubber removing ash from flue gas was also made at Pasadena Power and Light Company.

The following types of scrubbers were evaluated:

- Cyclone
- Impingement Plate
- Packed Bed
- Venturi
- Nozzle
- Turbulent Contact
- Flooded Bed
- Spray Tower
- Cross Flow

Scrubbers recommended for evaluation in the test facility are:

- Venturi Scrubber followed by an absorption section
- Flooded-Bed Scrubber
- Turbulent-Contact Scrubber
- Impingement-Plate Scrubber.

The criteria used for selecting the scrubbers are:

- Estimated efficiency of sulfur oxides and particulate removal
- Pressure drop
- Turndown capability
- Plugging characteristics
- Mist elimination
- Scrubber liquor requirement

It is believed that the scrubbers chosen meet these criteria best. Table 6 - 5 summarizes the information used in making the recommendations and indicates data required to be determined in the test program.

Based on a literature search, limited mass-transfer data are available. The data reported were for SO_2 concentrations 1 to 15 percent, higher than that anticipated for feed gas to the test facility. Mass transfer data will be obtained in the test program and correlated as discussed in Section 6 to serve as a basis for full-size units.

2.3 TEST PROGRAM

The test program for the limestone injection-scrubbing process will investigate sulfur oxides and particulate removal from flue gas. Nitrogen oxide reduction will also be measured. The preliminary test program described in this report will be developed into a detailed test program in Phase II.

Principal objectives of the test program are:

1. Measure, evaluate, and compare the mass transfer capability of the selected scrubber designs
2. Develop scrubber performance data and correlation of variables that can be used to design commercial scrubbing systems
3. Measure, evaluate, and compare particulate removal efficiencies of the selected scrubber
4. Determine the most favorable operating configuration for the solution slurry circuit
5. Determine performance characteristics of the clarifier, vacuum filter, and centrifuge
6. Measure, evaluate, and compare the operation of three types of flue gas reheaters
7. Determine accurate overall material and energy balances
8. Identify, evaluate, and solve problems related to mechanical design
9. Point out where small-scale supporting research is needed to help accomplish program objectives

The test program will be divided into four parts:

- Initial startup
- Calibration and performance testing
- Screening experiments
- Primary experiments

Table 14-1 summarizes the major objectives of the test program. It also describes measurements to be made, analytical techniques to be used, and how to apply these data to commercial design. The program as planned covers a period of 16 months: two months each for the first three parts of the program and ten months for the primary experiments.

A staff of 41 engineers, operators, and technicians will be required to operate the test facility 24 hours per day. The cost of the test program is estimated at $2,314,000.

2.4 ENGINEERING AND PROCESS DESIGN

The design criteria for preliminary engineering of the test facility are summarized below:

> The site selected for the test facility was Detroit Edison Company's St. Clair Power Station, St. Clair County, Michigan.
>
> Boiler No. 1 at the St. Clair Station will be equipped with the experimental scrubbing systems.
>
> One half of the boiler flue gas will be scrubbed in the test facility while the other half will pass through the existing dust collector, induced-draft fans, and stack. The flue gas leaving the south air preheater of the boiler will be diverted to the three paralled scrubber systems. Each scrubber system will consist of the

scrubber proper, necessary flue gas duct-work, a flue gas reheater downstream from the scrubber, an induced-draft fan, and a stack. It will also consist of an effluent-handling and recirculation system for the scrubber, including a clarifier, a vacuum filter, and a centrifuge. Control of flue-gas-handling dampers and induced-draft fans will be by power plant operators. The test facility will be operated by separate personnel.

In order to inject additive, one of the coal bunkers will be modified. A gravimetric feeder will be installed to permit measurement of additive feed rate.

The modifications of the steam-generating unit consist of reactivation of the soot blowers and modification of the flue gas duct system and pulverizer.

Data supplied by Detroit Edison on coal consumption, ash composition, heating value of coal and estimated boiler heat-rate are listed in Table 11-1. The coal compositions indicate that the sulfur content of the coal varies from 2.5 to 4.5 percent. The average value is 3.3 percent.

Equipment design was based on handling the flue gas and particulates that would be injected when highest sulfur-content coal was used. The highest stoichiometric feed rate of additive will be 250 percent.

Each scrubber will be designed for a flue gas rate of 100,000 acfm, at 375F and 14.3 psia.

Material balances were calculated and are presented in Tables 11-4 through 11-6 and Figures 3-5, 3-6, and 3-7. Material balances are based on 90% SO_2 removal at 130% of stoichiometric and 95% with injection at 250%. Particulate removal is 99%.

Based on the above design criteria, preliminary piping and instrument diagrams were developed for each scrubber train. These are shown in Figures 3-5, 3-6 and 3-7. Other drawings prepared were:

- Plot plan
- One line electrical drawing
- Duct drawings
- Equipment layout

Preliminary specifications were developed for all major equipment and are summarized in the Appendix A Equipment List.

The test facility design includes all necessary instrumentation to carry out a detailed test program and a data acquisition system.

2.5 COST ESTIMATE

Based on the preliminary engineering described in this report, an order-of-magnitude cost estimate was prepared. The cost breakdown is shown below and includes escalation of labor and material costs thru 1970.

Total Field Cost	$3,595,000
Engineering	663,000
Home Office	187,000
Contingency	445,000
Escalation	205,000
Fee	255,000
Total Constructed Cost	$5,350,000

This cost estimate was higher than the anticipated cost of the facility. A subsequent study, Phase I-A, was therefore authorized to develop alternative process designs that have lower cost but still meet the basic program requirements. This phase, discussed in Section 17, consisted of the preparation of rough capital, operating, and restoration cost estimates for four alternative process schemes selected jointly by the NAPCA and Bechtel.

In agreement with the NAPCA, Bechtel selected the most promising design and prepared capital, operating and restoration costs to the same degree as the Phase I design. The lower-cost alternative facility chosen consisted of two independent scrubber trains. Its total constructed cost was estimated at $4,150,000 – a saving of $1,200,000 over the base case.

2.6 RESTORATION

At the request of the NAPCA, a restoration plan was developed to remove equipment and restore the site to its original condition after completion of the test facility operation. The estimated cost of restoration, including credit for salvage, is $600,000. The estimated restoration cost for the reduced-cost alternative facility is $500,000.

2.7 CONSTRUCTION

A preliminary construction schedule was prepared, matching construction activities with the planned Detroit Edison maintenance program for the boiler. The construction schedule indicates a time requirement of 18 months from start of Phase II work until startup of the test facility.

2.8 ADDITIONAL DESIGN CONSIDERATIONS

The following design concepts have not been included in the preliminary designs. However, they should be considered further before completing the final design.

- Provide sprays for saturating inlet gases to the scrubber. This may help prevent plugging due to evaporation and solids crystallization

- Provide means for controlling the temperature of scrubber liquor
- Provide means for dissolution of lime outside the scrubber solution circuit
- Provide additional piping and internals for the venturi scrubber to allow separation of the effuent from the venturi proper and absorption section, as described in Section 6

Section 3

PLANT DESIGN DESCRIPTION

The Alkali Scrubbing Test Facility, the preliminary design for which is presented in this report, is to be installed at the Detroit Edison Company's St. Clair Power Station, St. Clair County, Michigan. Experiments are to be performed on equipment installed on and around Boiler 1. The location of the facility is shown in Figure 3-1 at the end of this section.

The plant design is here described in process sequence, beginning with the Additive Storage and Handling Facilities where the additive (limestone or dolomite) is brought into the plant. Individual pieces of equipment are identified by the equipment numbers shown on the Piping and Instrumentation Diagrams (P&ID's) and in the Equipment Lists in Appendix A.

3.1 ADDITIVE STORAGE AND HANDLING FACILITIES

The additives (limestone or dolomite, or both) are stored in area 1 (see Figures 3-1 and 3-2) on the west side of the coal crusher house. Trucks dump the precrushed material in the designated area, where it is built up by a front-end loader (T-3) into a live pile over the transfer hopper (D-1). This hopper is located underground near the northwest corner of the crusher house. The 12-foot-square hopper has a steel-bar grating capable of supporting either loaded trucks or the front-end loader. The sloping sides of the hopper direct the material to the central opening above a Redler-type conveyor (T-1) located at 2, which runs 10 feet below grade at the feeding point.

A concrete structure surrounds the feed hopper and conveyor drive mechanism. The Redler conveyor is an "L" type unit, 19 inches wide and 60 feet long, with a 160-ton-per-hour capacity. (This type is being used extensively in handling bulk materials.) Flow from the hopper to the conveyor is controlled or shut off by use of the hopper discharge gate (D-2). The hopper pit is drained by the additive-storage-hopper sump pump (G-1).

The arrangement of the storage pile transfer hopper and Redler conveyor in relation to the existing crusher house is shown on Figure 3-3.

The Redler conveyor feeds the additive through an opening cut into the western wall of the crusher house via a new conveyor discharge chute (M-1). From here on, the additive is handled by existing materials handling equipment. The chute feeds conveyor 1, which in turn discharges onto the inclining conveyor 3, feeding the coal bunkers.

The coal conveyor system has a capacity of 800 tons per hour. However, during the limestone transport operation, the capacity will be limited to 160 tons per hour by the Redler conveyor. Depending on the load and other conditions discussed above, additive transport will require a maximum of two hours per day running time on conveyor systems 1 and 3.

In order to provide storage capacity inside the boiler house, one of the coal bunkers of unit 1 will be modified. Since the additive grinding is designated to take place in mill 3, which is the centrally located (so-called spare) mill of the five pulverizers serving boiler 1, the centrally located coal bunker among the five feeding these pulverizers will be modified for additive storage. The details of the bunker modification plan are shown in Figure 3-4. It is expected that, in case of emergency, the test program will be interrupted on a short notice, and mill 3 switched back to coal feed. To accommodate the additive, the bunker is partitioned so that it can store both additive and coal separately, with additive stored in an area surrounded by gunited steel partitions on three sides and the existing east wall of the bunker on the fourth side. New bunker partitions are items M-2, 3, 4, 5, 6, and 7 on the isometric view of Figure 3-4.

3.2 FLUE-GAS HANDLING SYSTEM

For the duration of the flue-gas scrubbing experiment, half of the flue gases generated in unit 1 will be diverted to the scrubbers. The other half will continue through the existing precipitators, ID fans, and stack.

The flow of diverted gas through the scrubbing system is illustrated on the Piping and Instrumentation Diagrams, Figures 3-5, 3-6, and 3-7. The location and arrangement of the bypass duct at the flue-gas outlet is shown on Figures 3-8, 3-9, and 3-10.

In order to divert half of the flue gases, a duct is attached to the existing gas duct, branching off ahead of the southern dust-precipitator inlet.

The design of the ductwork is such that relatively high gas velocities are maintained throughout the system. These high velocities are accepted partly by necessity, due to the limited space available at the branchoff point, and partly by choice, in order to prevent excessive precipitation of fly-ash in the extended ductwork. An elevation of the duct is shown in Figure 3-11.

Precipitator slide gates (M-9, 10, 11, 12, and 13) divert the gas flow at the precipitator inlet. Five gates, each about 8 feet long and 5 feet high, are provided. Each gate is operated by a standard rising-stem motor operator (K-1, 2, 3, 4, and 5), Limitorque or equivalent. The gates are guided at the sides to prevent jamming. The guides are attached to the gates proper and are therefore withdrawn with the rising gates.

The design must be such as to prevent dust accumulation, which could interfere with gate operation. A preliminary design of one approach is shown in Figure 3-12.

The bypass ductwork (M-14) begins between the east wall of the boiler house and the south precipitator inlet at 3, Figure 3-1. A four-foot gap exists between these two, which requires a 25-foot-high duct to provide the cross-sectional area that is needed so as not to exceed the design velocity. Flue gas leaving the air heaters is diverted into the duct when slide gates close the precipitator inlet. A 3-foot, 9-inch by 25-foot double-bellows expansion joint (M-15) is provided in the duct to accommodate differential expansion.

The duct is designed to retain over 3000 fpm velocity when 282,000 cfm of flue gas pass through it. This velocity is low enough to keep the pressure drop acceptable.

From the large bypass ductwork, three branch ducts are provided, each serving one of the scrubbers 4, 5, and 6 on Figure 3-1. The branches are perpendicular to the main duct, and equipped with inlet guide vanes to reduce friction loss. It is expected that these vanes will assure a stable velocity distribution in the gas streams so that the ductwork preceding the scrubbers can be equipped with dependable flow-measuring devices.

In order to assure a complete and quick separation of the scrubber equipment from the main gas passage, multiple-leaf dampers are provided at strategic points. The first damper is located in the main bypass duct handling the full bypass gas flow. The damper dimensions are approximately 25 feet by four feet. This damper is remotely operated from the boiler control room and permits the unit operator to isolate the scrubber systems quickly and revert the flue gas flow through the slide gates into the south precipitator.

The two partitions that comprise the north and south sides of the modified bunker extend straight down 44 feet, to within eight feet of the feed-hopper outlet. From there they follow the slope of the existing hopper. The partition on the east side extends straight down 27 feet and then slopes down until it intersects the centerline of the bunker, bisecting the rectangular outlet into two square outlets. Steel stiffening-members are welded to the partition walls. The stiffeners are shielded to assure an even flow of material through the bunker.

The feed hopper outlet is modified to provide a dual mill feeding arrangement. A new discharge chute (M-8) is attached to the lower end of the bunker. This arrangement permits additive material to be fed through a bunker gate assembly (D-3) from the east outlet into a gravimetric feeder (T-2). The material passes from the feeder through a 22-inch discharge pipe junction (L-2) to pulverizer 3. Coal can be fed from the west outlet of the bunker through bunker gate assembly (D-3) and a 22-inch discharge pipe (L-1) to pulverizer 3. The centrally located spare mill (mill 3) will be used for additive introduction as described on page 3-2. The pulverized additives will be introduced through the four existing upper burner ports into the furnace.

The volumetric feeders on the existing pulverizers have an accuracy of about ± 10 percent. This accuracy is inadequate for the purpose of the test program, and it is recommended that a modern gravimetric feeder (T-2) with ± 1 percent accuracy be installed in the additive feed pipe, permitting more accurate monitoring of the additive flow. The control of this feeder will be incorporated into the pulverizer control of mill 3 for the duration of the test program. This will provide parallel adjustment for both material feed and primary air flow.

It is recommended that the old feeder be kept intact and remain with the existing combustion control equipment. If the mill has to be returned to coal operation as a standby for the other four pulverizers, the boiler can be run undisturbed, and the test program temporarily interrupted. For additive feed, the new gravimetric feeder will be controlled by remote manual control from the boiler control room and the old volumetric feeder set at maximum feed rate so as not to interfere with the additive flow. The primary air-fan-damper setting will always be tied to the active feeder control.

It is expected that increased dust loading will require periodic soot-blowing in the second passage of the steam generator. Interspersed with the secondary heat exchanger surfaces in this passage are five pairs of soot-blowers, which at present are inoperative, with a few dismantled. It is recommended that these soot-blowers be reactivated and tied to the existing compressed-air network serving the soot-blowers. No steam should be used for soot blowing, as the lime in the fly-ash may react and generate hard deposits between the tube banks. Experience on unit 6 during the earlier scrubber experiments dictates caution against steam blowing or wet washing of these surfaces. Aside from the reactivation of the soot-blowers, the steam generator proper will not require any modification.

Dampers at the inlets of each of the flue gas supply ducts to the scrubbers (shown as M-16, 17, and 18 in Figure 3-8) serve a dual purpose. They permit the isolation of individual scrubber systems for maintenance while the other scrubbers are still in operation. They also provide for a pre-selected gas distribution among the scrubbers, in that they are tied to the boiler draft control.

If one of the scrubber systems is equipped with a regenerative reheater, then the heat extractor of the reheater system will be accommodated in an enlarged portion of the supply duct. After the heat extractor, the flue gas duct enters the scrubber. After the scrubbers and mist eliminators, the flue gas passes through outlet ducts M-19, 20, and 21, and through induced draft fans K-101, 201, and 301. The fans have spare capacity to provide for experimentation with the scrubbers.

It is suggested that these fans should not have any control other than the automatic damper control in the scrubber-inlet ductwork. The simplicity of this arrangement should compensate for the slightly increased power demand at partial load. Each fan exhausts directly into an individual steel stack.

The arrangement of the ductwork is shown in Figures 3-8 and 3-9 and the individual flue gas passages to the scrubbers in Figures 3-8, 3-9, and 3-10.

3.3 STACKS

Flue gas that has been scrubbed and reheated by the appropriate equipment is emitted to the atmosphere through three separate stacks (F-1, 2, and 3) — one for each system. The stacks are of steel and about 150 feet high. An exit velocity of about 100 feet per second was used to calculate the stack diameter, which is five feet at the exit. A 10-foot diameter at the stack bases was selected for structural stability.

For a concentration of SO_2 at the ground of 0.2 ppm, the required stack height was calculated (after Bosanquet) to be below the 150-foot height selected. Since it is good practice to install stacks as high as or higher than surrounding structures, the height of 150 feet was retained. At this height, the ground concentration of SO_2 is calculated to be less than 0.10 ppm at a distance of approximately 1-1/2 miles downwind from the stack.

3.4 SCRUBBER SYSTEMS

Detailed P&ID's for the three scrubber systems are shown in Figures 3-5, 3-6, and 3-7. Since these systems are similar, a detailed description is presented for only one system. Differences between the systems are then described.

3.4.1 Plant 200 System

Figure 3-6 presents in detail the plant 200 system utilizing the TCA scrubber (C-201). In the following paragraphs, the flue gas flow is described first, then the liquid flows. Alternate modes of operation are also described. Numbers in diamonds above the main process lines in Figures 3-5, 3-6, and 3-7 refer to the material balances presented in Tables 11-4, 11-5, and 11-6. These balances indicate flows through the main process lines for varying operating conditions.

Flue gas enters the scrubbing system through the inlet duct of the main gas manifold. Flowrate is measured with a venturi meter. A damper located after the venturi is used for flow control. During normal operation, this damper is controlled by a signal from the venturi. It is connected to a priority selector that determines which of the scrubber systems will have priority for gas entering the main manifold. Details of this priority selector are discussed in Section 12, Instruments and Controls. After the gas passes through the dampers, measurement is made of temperature, pressure, and dust loading, and of sulfur dioxide, sulfur trioxide, carbon dioxide, oxygen, water, and nitrogen oxides concentrations. Dust-loading measurements are made by isokinetic sampling. Gas temperature at this point is approximately 275 F. After entering the scrubbers, the gas duct bends downward. This is to prevent solids buildup in the gas inlet.

The gas, after entering the scrubber, passes through two turbulent-contact stages, such as those designed by Universal Oil Products Corporation. Provision has been made for addition of a third stage at a later date. Sample-taps have been provided at the top of each contacting section. The gas exits through a mist-elimination section and enters the outlet duct.

At the outlet duct, pressure, temperature, and the same gas components as were measured at the inlet are measured, using the same analytical instrument. The gas then passes through a steam reheater (E-201), which has the capacity to increase flue gas temperature from 125 F to 274 F. This broad temperature range is recommended in order to accommodate experiments with the reheater. After the reheater, measurement of dust loading and pressure are made. The gas then passes to an induced-draft fan (K-201). At the fan outlet, temperature is measured again. A signal from this temperature sensor is used to control the quantity of steam fed the reheater. The fan exhausts directly through the stack.

Water and solids at approximately 125 F leave the scrubber through a 16-inch diameter pipe and enter the scrubber effluent hold tank (D-201). The pipe is large enough to avoid plugging. The tank is stirred with a mixer (Y-203) at a rate that keeps smaller particles in suspension. Particles larger than about 1/16-inch in diameter settle to the tank bottom. A screw conveyor (T-205) at the bottom of the tank periodically removes these solids. Temperature and pH of the liquid in the tank are measured. Two level-controllers are provided on the tank. During normal operation, the lower level-controller controls the valves on the scrubber effluent pumps (G-201, 202). The upper level-controller is described in Section 13.8, Operation During Malfunction.

The two effluent pumps, which pump the liquid from the effluent hold tank, are each sized to handle 75 percent of the maximum flow anticipated in the system. This ensures maintenance of liquid flow in the case of pump failure or the plugging of a line. During normal operation of the effluent hold tank, the liquid is pumped to the clarifier (D-202). Flow is measured with a magnetic-type flowmeter and the concentration of suspended solids with a radiation-type density meter.

In the clarifier, the liquids and solids are separated. Clear liquid overflows the clarifier and passes by gravity to the process-water hold tank. Solids settle to the bottom of the clarifier and are scraped to the center by a mechanically operated rake (Y-205). It is anticipated that the slurry leaving the clarifier will be composed of between 25 and 30 percent solids. The slurry is pumped to a rotary vacuum filter (Y-201), to a centrifuge (Y-202), or to a test settling tank (D-204). Two parallel pumps (G-203, 204) are used, each designed to handle 75 percent of anticipated maximum flow. During normal operation, it is anticipated that the vacuum filter or centrifuge will be used. The solids leaving the filter or centrifuge pass to the solids disposal area on a conveyor (T-204) equipped with a scale that gives a continuous readout of solids weight. Samples of the solids are taken and moisture content determined. The filtrate is pumped back to the process water hold tank (D-203) or directly to the drain. Filtrate flow is measured by an orifice meter. Pumping the filtrate to the drain simulates a mode of operation in which only a clarifier is used, without facing the problem of disposing of slurry with high water content.

During normal operation, the level in the process-water hold tank controls the amount of makeup water entering the system. This tank is provided with an agitator (Y-204) to keep any solids suspended. The pH of the liquid in this tank is measured.

Process water is pumped from this tank by two pumps, connected in parallel, back to the scrubber. These pumps (G-205 and 206), each capable of handling 75 percent of maximum anticipated flow, will assure some liquid flow to the scrubber should one pump fail. Sampling taps are provided in the process-water return line for taking samples for analysis. These samples are analyzed for concentrations of calcium, magnesium, iron, sulfite, bisulfite, and sulfate ions. The temperature, concentration of suspended solids, and flowrate are also measured. Flow is controlled at a present level during normal operation.

The scrubbing water is sprayed downward into the scrubber to give a countercurrent gas-liquid flow. As it passes down the scrubber, the water contacts the flue gas, absorbing sulfur dioxide and particulates. Since the system operates at total recycle, the water is nearly saturated with calcium, magnesium, sulfite, and sulfate ions. Absorbed sulfur dioxide is converted to sulfite and sulfate. When limestone is used as the additive, calcium sulfate and sulfite are precipitated in the scrubber. When dolomite is used, some magnesium sulfite and sulfate may also be precipitated.

The system has been designed so that several modes of operation other than the one described can be evaluated. If it is desired to recycle slurry to the scrubber, part of the liquid leaving the scrubber effluent hold tank can be pumped directly to the process-water hold tank, bypassing the clarifier. The bypass ratio is controlled by the concentration of suspended solids in the recirculating line. Flow of bypass liquor is measured by a magnetic-type flowmeter. It is also possible to pump the liquor leaving the scrubber-effluent hold tank directly to the filters, the centrifuge, or the settling tanks. This mode of operation will be tested when slurry recycle is used in the scrubber. Under these conditions, it might be possible to achieve a high-enough concentration of solids in the slurry leaving the bottom of the scrubber so that direct filtration or centrifugation would be possible. The centrifuge can be used to dewater the slurry coming from any of the three scrubber-effluent hold tanks. The solids would leave the centrifuge and pass to a conveyor, which would be equipped with a scale to give a continuous readout of the weight of these solids. The liquid would be pumped back to the process-water hold tank, its flow measured by an orifice-type flowmeter. Manifolding on the outlet of the liquid return pump (G-210) provides for returning the liquid to the proper hold tank.

The settling tank can also receive flow from any of the clarifiers or scrubbers. The solids accumulating on the bottom of the settling tank are periodically removed and weighed. Overflow from this tank is pumped back to the process-water hold tank. A manifold is provided for pumping the overflow from the settling tanks to any of the three scrubber systems. This flow is measured by orifice-type flowmeters. Piping to the settling tank is shown as fixed; however, it may be possible to use flexible temporary piping, since it is intended that it will be used only periodically.

3.4.2 Plant 100 and 300 Systems

The differences between the Plant 200 system just described and the Plant 100 and 300 systems lie essentially in the scrubber type and the flue-gas-heating arrangement.

The scrubber in Plant 100 (C-101), shown in Figure 3-5, has a venturi-type throat followed by an absorption section. For design purposes, a Universal Oil Products Venturi-Sphere was used. The flue-gas reheater is a gas-fired rather than, as in Plant 200, a steam reheater. Gas enters the top of the scrubbing unit, passes through the venturi (which has a variable throat), and through the absorption section (which consists of a turbulent bed of low-density spheres). After the absorption section, the gas passes through a chevron-type mist eliminator, exits through the side of the scrubber, and passes through the reheater. Flow through the reheater is controlled by the temperature of gas leaving the induced-draft fan after the reheater (K-101). Part of the process water enters at the entrance to the venturi through an overflow weir. This wets the venturi walls and prevents the buildup of solids. After leaving the venturi, this liquid is separated from the gas and leaves through the scrubber bottom. The rest of the process water is sprayed downward through the absorption section of the scrubber and also goes out through the scrubber bottom. Pressure sensors are provided at the exit of the venturi section and at the exit of the absorption section. Provisions have been made for addition of a second absorption section at a later date.

The scrubber in Plant 300 (C-301), shown in Figure 3-7, is a marble-bed type as manufactured by National Dust Corporation and called a Hydro Filter. The flue-gas heating is regenerative: gas entering the scrubber is cooled in a heat exchanger (E-301), and hot water from this exchanger is pumped to the reheater (E-302), where it heats the gas coming from the scrubber. The inlet to the Plant 300 scrubber has a wetted-wall section as manufactured by Peabody Engineering. A part of the recycling process water is piped to this wetted-wall section, entering the duct through an overflow weir. The gas, entering the scrubber at the bottom, passes up through a bed of marbles resting on a grid. The pressure drop across the marble bed is monitored. The balance of the process water (that is not split off for the wetted-wall duct section) is sprayed upward through the gas at the bottom of the scrubber. Water drops to the bottom of the scrubber through downcomers in the marble beds and is piped to the scrubber effluent hold tank (D-301). The gas passes upward through a vane-type demister, leaves through the top of the scrubber, and passes through the reheater.

Provisions have been made for the addition of a second marble-bed tray in the Plant 300 scrubber if this proves desirable. If this tray is added, a sampling system will also be provided for taking samples of liquid and gas between the two trays.

The shell used for the Plant 300 Hydro Filter unit will also be used for testing an impingement plate scrubber as manufactured by Peabody Engineering. The scrubber internals will be changed accordingly at some point in the test program. Figure 3-13 shows the configuration of this alternative scrubber. This unit contains two impingement baffle plates and a centrifugal mist eliminator. Provisions have been made for addition of another plate at a later date if this proves desirable. The process water for this unit is split into five streams: one enters the wetted wall section and flows to the bottom of the scrubber; three are sprayed into the scrubber, two below the bottom impingement plate and one below the top plate; and one flows onto the top plate over an overflow weir, down through a downcomer, across the bottom plate, and out the scrubber bottom.

3.4.3 General System Arrangements

General arrangements for the scrubbers are shown in Figures 3-8, 3-9, and 3-10. The inlet ducts to the turbulent contact absorber (C-201) and the National Dust Hydro Filter (C-301) have been located to give downward flow of gas just before it enters the scrubbers. In the case of the Hydro Filter, this has been done to accommodate the wetted wall section. The downward section at the entrance of the TCA unit can be converted to a wetted wall design if troubles with duct plugging are encountered.

The scrubber-effluent hold tanks are provided with side intakes for better settling hydraulics. The screw conveyors at the bottom of these tanks empty into bins sitting beside the tanks.

The layout of the clarifiers is shown in Figure 3-14. The clarifier underflow pumps have been located in tunnels underneath the clarifiers to maximize the inlet heat to the pumps and minimize the possibility of plugging. Piping from the scrubbers to the clarifiers and the filter building is run on an overhead pipe rack. Only the three main lines from the scrubber-effluent hold tanks and the three main return lines from the process-water hold tanks are run on the pipe rack. Manifolding is provided from these lines to and from the clarifiers, filters, centrifuge, and settling tank.

The filter building layout is shown in Figures 3-15 and 3-16. Solids from the filters and the centrifuge are conveyed to the main collection conveyor (T-206), which carries the material to a stacking conveyor that piles it in the solids storage area.

The water softening system, shown in Figure 3-17, provides a means for adding chemicals to the process stream at controlled rates. Two types of chemicals in solid form and one in liquid form can be added simultaneously to the chemicals mixing tank (D-401). This tank is supplied with water from the clarifier-overflow line and, after chemicals addition and mixing, discharges to the process-water hold tank. The details of operation when water softening is required are discussed in Section 13.2, Shutdown Procedure. Chemical addition other than for softening is also handled by this system. Chemicals added may include iron oxide for testing of catalytic effects, polyphosphates for pH control, and coagulants for improving the liquid/solids separation efficiency of the clarifier. By a portable liquid-chemical feed system, coagulants may be added to the scrubber hold tank, the vacuum filters, and the centrifuge.

3.5 CIVIL-STRUCTURAL DATA

3.5.1 Test Area Foundations

Geological reports of the site area indicate that the soil will not support the test facility loads without a pile foundation driven to bedrock. Therefore, piles and grade beams covered by a slab extending over the entire scrubber test area will be used. Pipe piles of 100-ton capacity, such as Raymond "Step Taper," will be driven to the hardpan that is approximately 125 feet belowground. The piles will be topped by concrete caps and framed by grade beams. The beams will span 20-foot pile centers and support a reinforced concrete slab. A pattern of piles and grade beams will cover the site area as shown in Figure 3-18.

Equipment pedestals for major pieces of equipment, such as for the induced draft fans with their drivers, will be poured on top of the slab and removed after the test program is completed. This can be accomplished by placing a bond-breaker between the slab and the pedestal and bolting the pedestal to the slab.

3.5.2 Clarifier Foundation

To prevent a blowout due to groundwater pressure when the clarifier tanks are emptied, these tanks will be supported on a crushed-rock base to allow groundwater drainage. The bottom of the clarifier tanks will be of compacted impervious fill, covered by steel sheets to prevent erosion during washdown operations. The tunnel to the central rake-support pier will be a flexible corrugated-metal pipe designed to yield with the soil settlement anticipated during the test period. The central rake-support pier will be formed by short friction sheet piles, designed to keep differential settlement of all elements to a minimum.

The clarifier foundation details described above are the most economical solutions for the specified two-year service period. The system can be readily dismantled and the site returned to the original condition at the conclusion of the test program.

It is imperative that a comprehensive soil testing program be completed at exact structure locations prior to establishing final design plans. Should such soil testing indicate the need, foundation details will be revised to incorporate piles and a rigid concrete clarifier-tank bottom and tunnel.

3.5.3 Filter Building Structure

Building. The filter building will have a rigid, prefabricated frame of length, width, and eave height as shown in Figure 3-15. Bracing, wind bents, framing for openings, and all other structural members, anchor bolts, and base plates will be included with the prefab package.

The foundation and floor slab will be poured integrally with a perimeter grade beam. They will be detailed as a basic permanent installation and will incorporate a slab on an elevated crushed-rock base to minimize frost heave. A certain amount of long-term settlement is anticipated, however, because of the weak clay subsoil material. Equipment foundations will be constructed on the existing grade surface.

Building Loadings. Roof loading is designated as 40 pounds per square foot of live load, with a wind load of 25 psf below 30 feet and 30 psf above 30 feet. An allowance for pipe loads is made in the structure design.

Building Cover. All exterior building cover will be Inland 26-gauge galvanized Type AW panel, or equal, supported by girts at approximately 4-foot centers and by roof purlins at approximately 5-foot centers.

Insulation. The entire building will be insulated between the exterior sheeting and girts or purlins with 2-inch thick, 3/4-pound-density, fiberglass insulation with foil-scrim craft (also known as reinforced foilfaced craft) backing. The "U" factor of this insulation, when applied in the manner described, is 0.136 or better.

Wainscoating. Wainscoating will be provided for the bottom 10-foot inside surface of the building walls with 22-gauge Inland Type AW panel, or equal, bonderized and painted. For proper breathing, panel corrugation ends will be left open, that is, not sealed with closures.

Translucent Siding. Translucent panels will be equal to H. H. Robertson Company Type SME Stypolight in aqua, of standard weight with corrugations to match the siding configuration.

Service Doors. Service doors will be of flush, hollow metal, with 20-gauge-steel face sheets. They will be 1-3/4 inches thick, stiffened, and sound deadened. Door frames will be pressed metal, of 16-gauge steel, mortised and reinforced for strikes and hinges. Hardware will be mortise-type, conforming to #86-B-4 of Government Specification FF-H-106A. Doors will be of the number and size shown in Figure 3-15.

Ice Canopies. Ice canopies of 1/4-inch-thick plate steel will be provided. They will be supported by angular external bracing back to the building foundation.

Truck Door. The insulated vertical-lift truck door will be of the same gauge as the building cover sheets, with a "U" factor of 0.136 or better. Guides, tracks, locksets, and all necessary hardware will be included.

Building Service (Heating and Ventilating). Heating will be provided in the building by steam unit-heaters, sized to maintain a minimum temperature of 55 F. Each heater will be thermostatically controlled. Ventilation will be provided by louvers and gravity roof-ventilators.

3.5.4 Foundation Design — Additive Conveyor Pit

The conveyor pit shown in Figure 3-3 will be founded as a spread footing on the weaker clay strata underlying the stronger desiccated crust. The pit will be protected against flotation by granular backfill draining via perforated pipe into the sump and pumped out with sump pump G-1. Differential settlement of the pit will be compensated for by adjustable machine supports. A soil test will be made to determine the magnitude of anticipated settlement, and the pit will be founded on piles if the soil tests indicate the likelihood of excessive settlement.

3.5.5 Bunker Modification

The bunker modification for the additive storage will consist primarily of the addition of a three-sided bin inside the existing bunker, utilizing one existing common wall and hopper bottom. The steel plates of the added partitions will be stiffened by vertical members that will in turn be framed into horizontal rigid frames. These rigid frames will incorporate struts spanning the bunker to resist drag-down loads. Wear points will be protected by abrasion-resistant plates and members will be self-cleaning.

3.6 ELECTRICAL POWER SYSTEM

The electrical power system is designed as a self-contained unit of sufficient capacity to supply power and lighting at the various required voltages. During periods of full-load operation, power requirements are approximately 3000 kva. A single-line diagram of the system is shown in Figure 3-19.

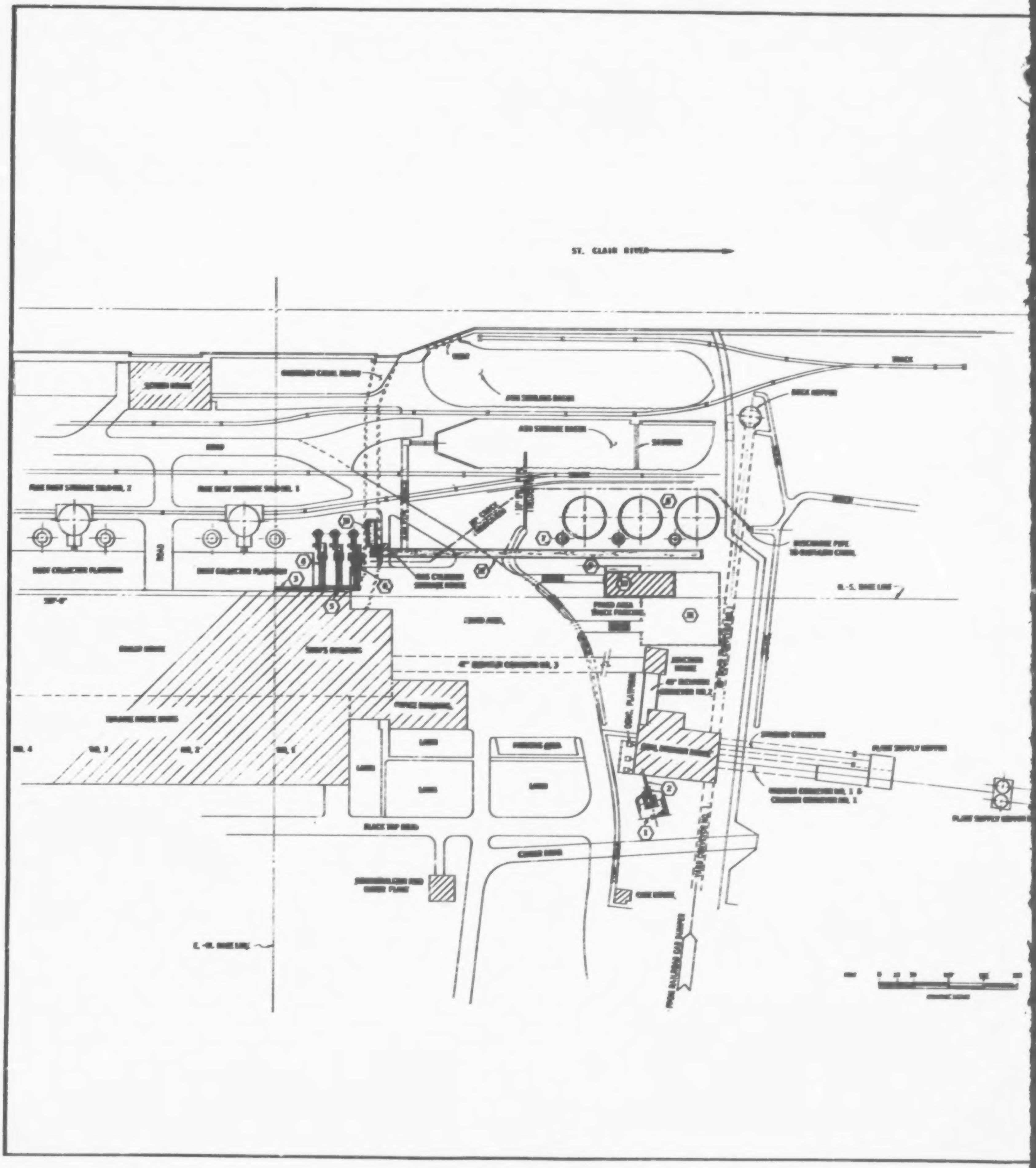
Power is obtained from the load side of an existing circuit breaker, which is connected to an existing 2400-volt plant bus. It is transmitted by cable to the 2400-volt switchgear of the SO_2-removal facility, where it is distributed to 2400-volt and 480-volt systems. At this distribution point, the power supplied is metered.

Connected to the 2400-volt bus are four sections of 2400-volt drawout switchgear, supplying power to the three 2400-volt induced-draft fan motors and the 1000-kva, 480-volt power transformer. Power from this transformer is distributed by the load center distribution panel, through the main distribution panels, to the subdistribution panels located throughout the facility. Each subdistribution panel is located in the area it serves.

Motors throughout the facility are controlled by motor starters mounted adjacent to each motor. Each starter is enclosed in a weatherproof enclosure, with start-stop push buttons installed in the enclosure cover. Local push-button stations are provided adjacent to the induced-draft fan and the slide-gate operating motors. Transformers of 25-kva, 120/208-volt capacity supply power to the plant lighting units. To minimize noise and disturbance, instrument power is supplied from a separate single-phase, 10-kva, 120/208-volt transformer.

Because of the distance separating the additive-handling facility and the SO_2 project proper, a separate power source has been provided in the limestone storage area. Power supplying the handling equipment in this area is obtained from the adjacent coal-handling building. A distribution panel is provided to distribute 480-volt power to both the handling equipment and the lighting transformer — a 10-kva single-phase unit supplying 120/208-volt lighting power to the area. Metering facilities are provided for metering the power supplied to the additive-handling equipment.

The facility will be floodlighted for general illumination, with supplemental local lighting where required. Light levels vary from approximately 5 to 10 footcandles for general illumination to 50 to 60 footcandles for specific seeing tasks. Wide-angle, color-improved, mercury-vapor units provide general area lighting. Hot-filament units provide localized lighting.


ST. CLAIR RIVER
TRACK
TRUCK HOPPER
ASH STORAGE BASIN
ROAD
DUST COLLECTOR PLATFORM
DISCHARGE PIPE TO OVERFLOW CANAL
N.-S. BASE LINE
PAVED AREA TRUCK PARKING
JUNCTION HOUSE
CONC. PLATFORM
PLANT SUPPLY HOPPER
NO. 4
NO. 3
NO. 2
NO. 1
LAWN
PARKING AREA
LAWN
LAWN
LAWN
BLACK TOP ROAD
GATE HOUSE
E.-W. BASE LINE
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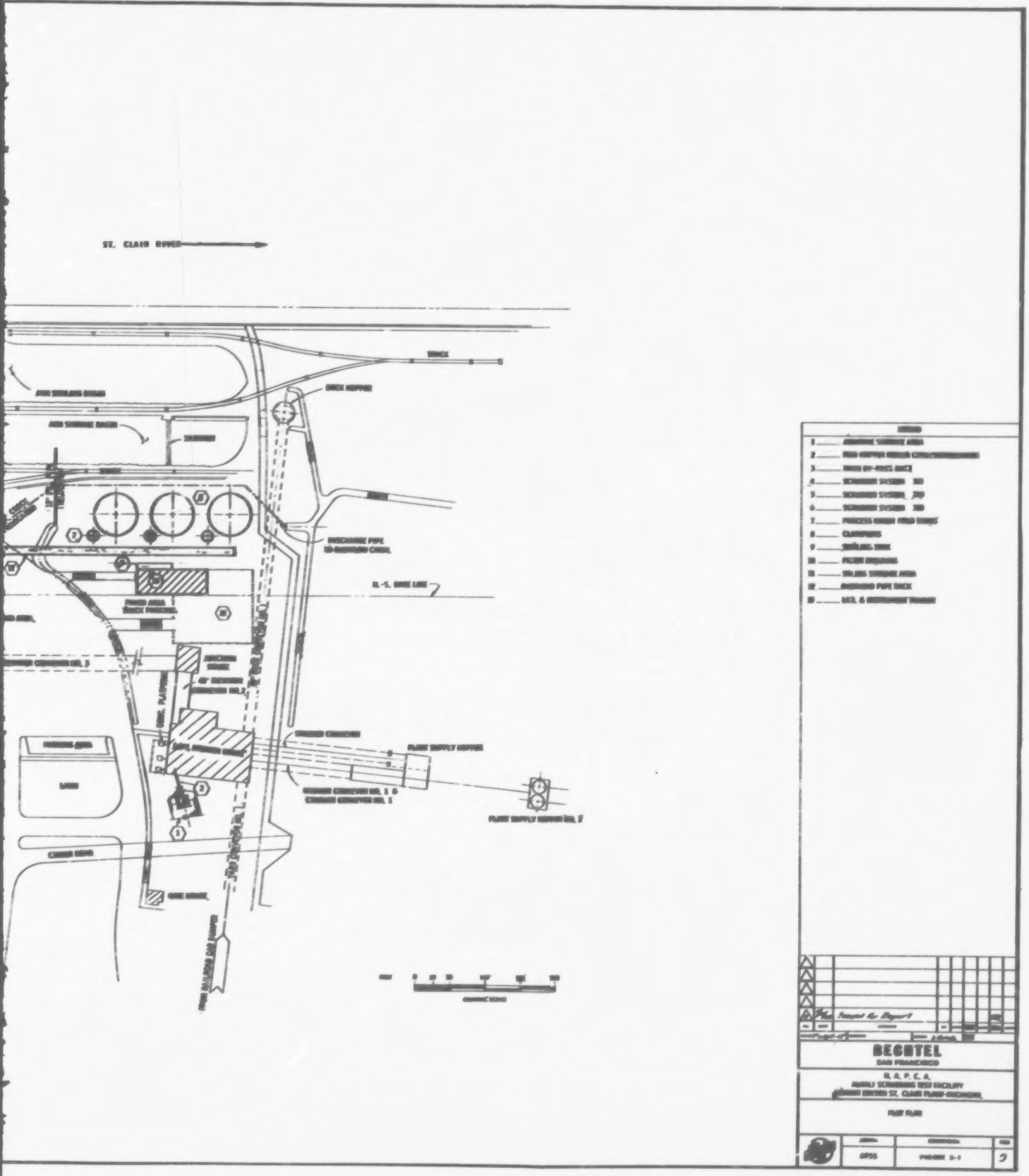
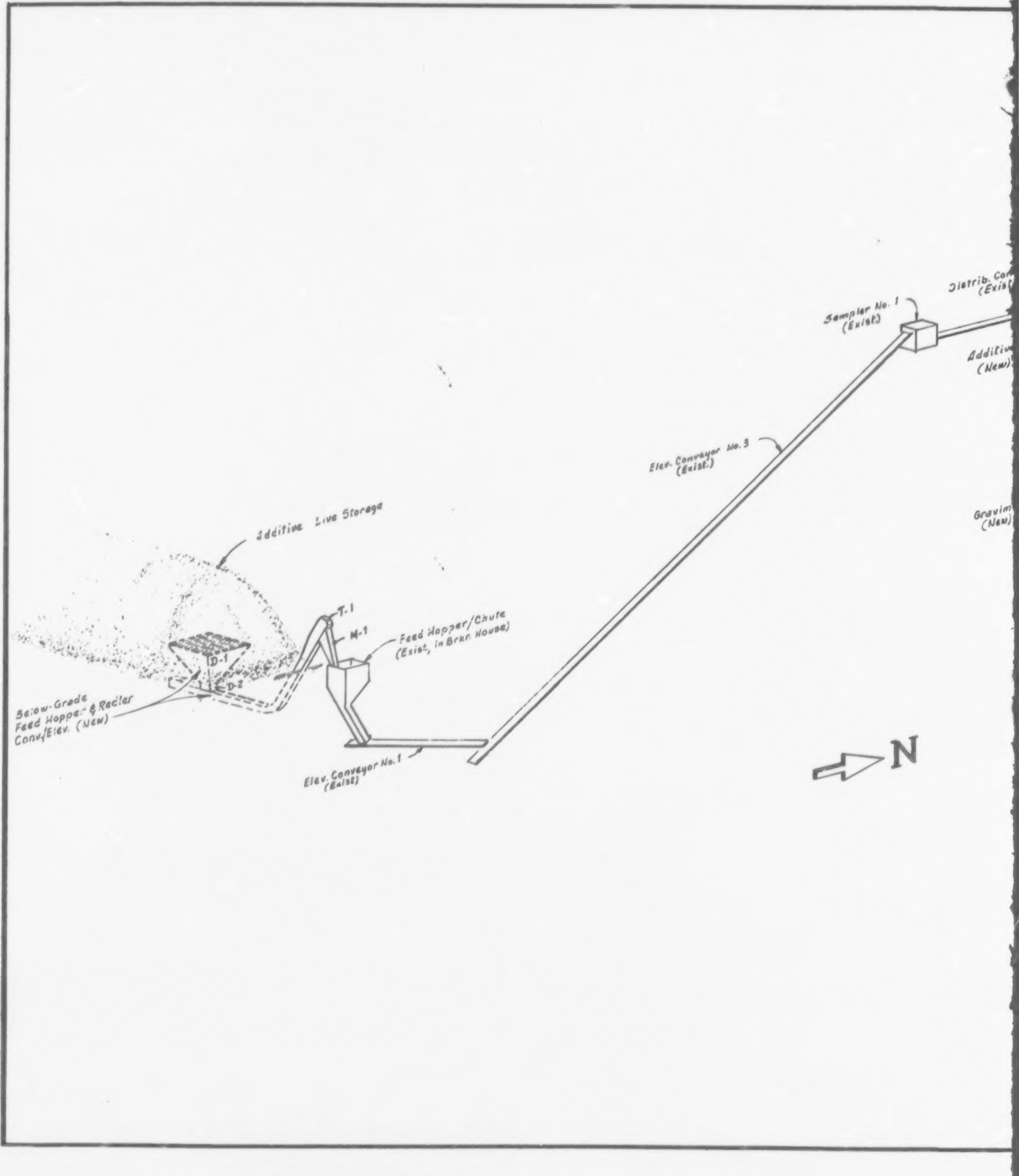
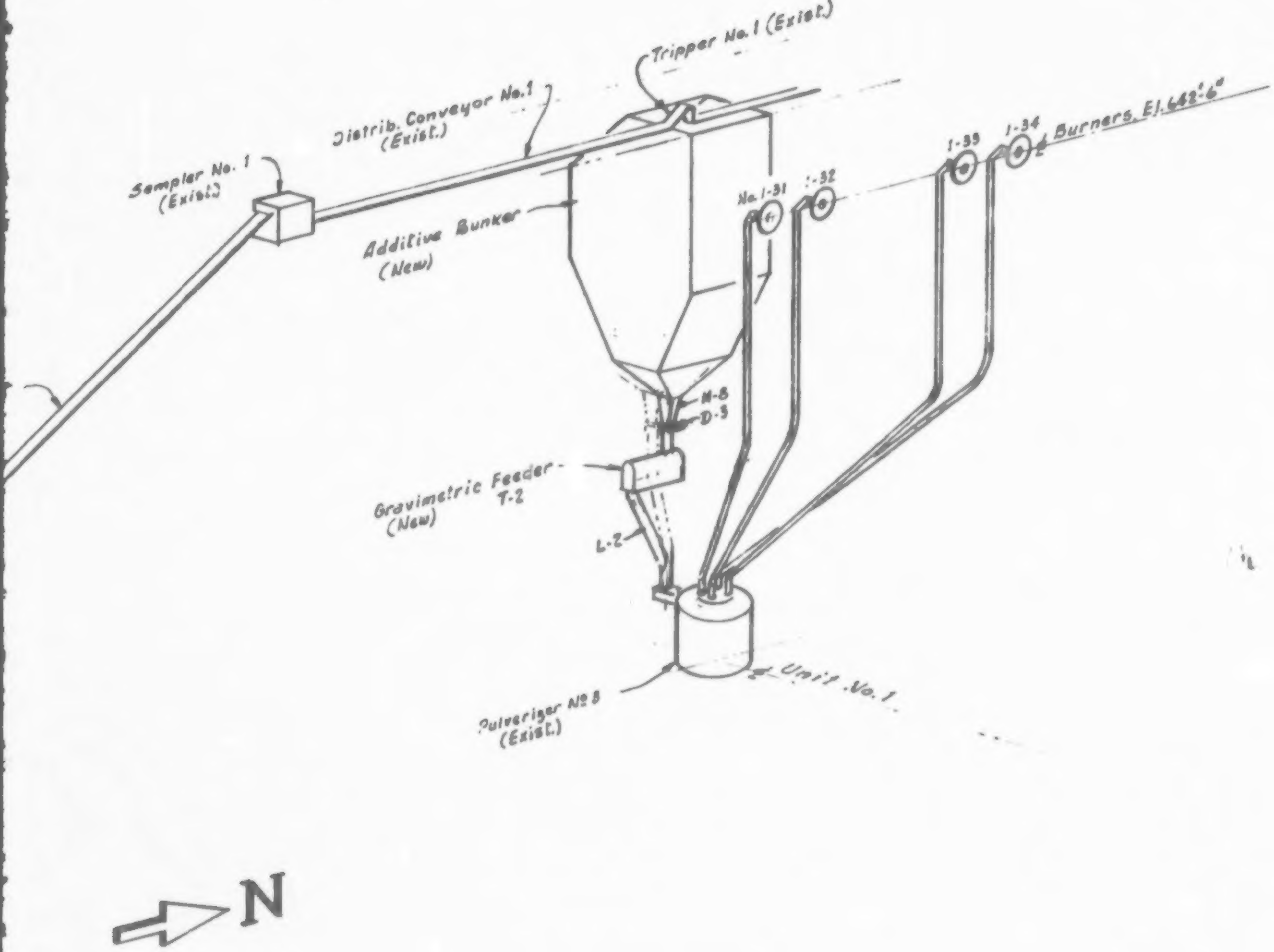
A


ST. CLAIR RIVER
TRACK
DOCK HOPPER
ASH STORAGE BASIN
DISCHARGE PIPE
N.-S. BASE LINE
PAVED AREA
TRUCK PARKING
PLANT SUPPLY HOPPER
LEGEND
1 ADDITIVE STORAGE AREA
3 MAIN BY-PASS DUCT
4 SCRUBBER SYSTEM
5 SCRUBBER SYSTEM
6 SCRUBBER SYSTEM
7 PROCESS WATER HOLD TANKS
8 CLARIFIERS
9 SETTLING TANK
10 FILTER BUILDING
11 SOLIDS STORAGE AREA
12 OVERHEAD PIPE RACK
13 & INSTRUMENT TRAILER
Issued for Report
BECHTEL
SAN FRANCISCO
N.A.P.C.A.
ALKALI SCRUBBING TEST FACILITY
DETROIT EDISON ST. CLAIR PLANT-MICHIGAN
PLOT PLAN
6935
FIGURE 3-1
9

B


Sampler No. 1
(Exist.)
Distrib. Con
(Exist
Additiv
(New)
Elev. Conveyor No. 3
(Exist.)
Gravim
(New)
Additive Live Storage
T-1
M-1
Feed Hopper/Chute
(Exist. in Brkr. House)
D-1
D-2
Below-Grade
Feed Hopper & Recler
Conv/Elev. (New)
Elev. Conveyor No. 1
(Exist)
N

A


Tripper No. 1 (Exist.)
Distrib. Conveyor No. 1 (Exist.)
Sampler No. 1 (Exist.)
Additive Bunker (New)
No. 1-31
1-32
1-33
1-34
℄ Burners, El. 642'-6"
M-8
D-3
Gravimetric Feeder T-2 (New)
L-2
Pulverizer No 8 (Exist.)
℄ Unit No. 1
N

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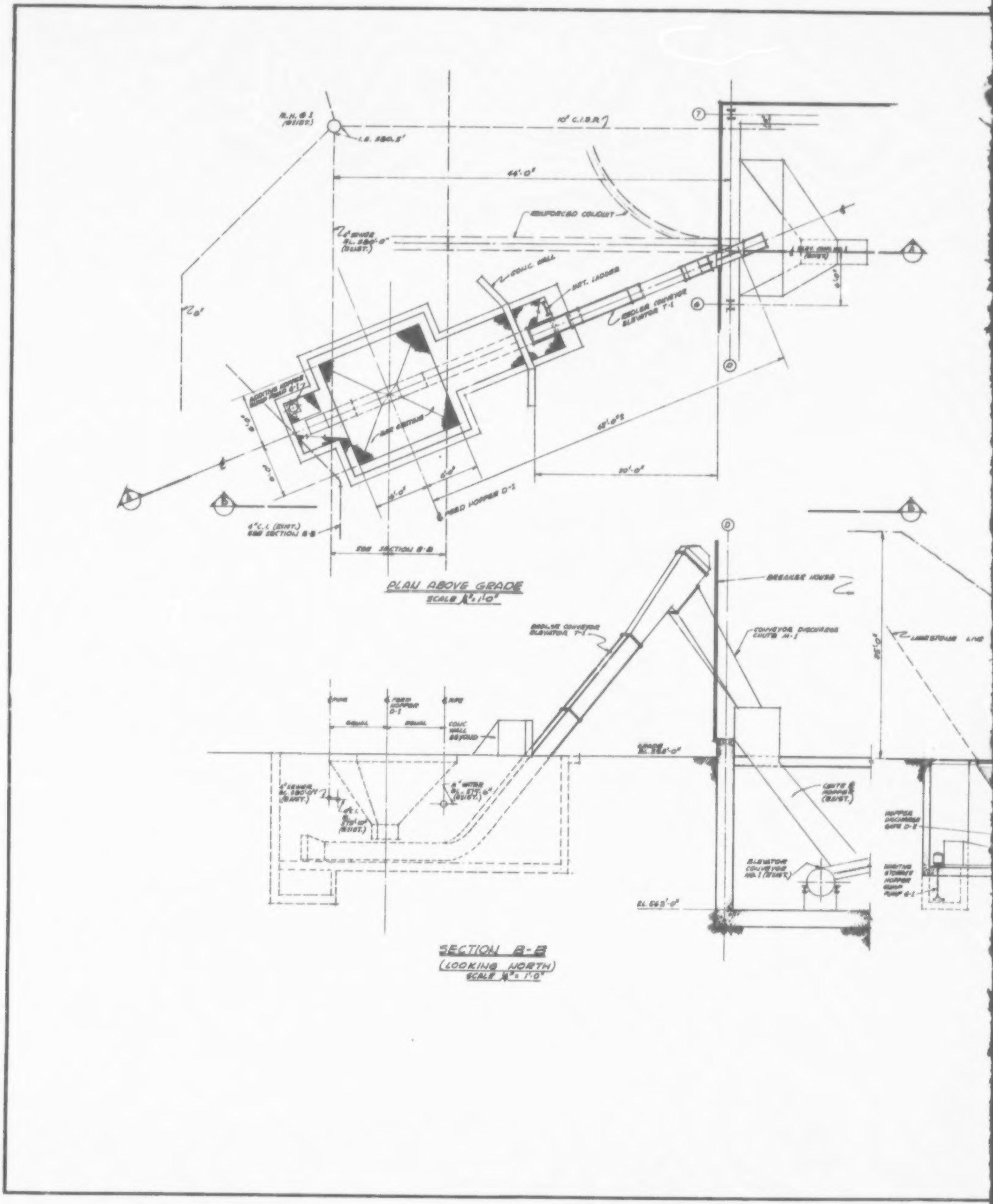
SAN FRANCISCO

N.A.P.C.A.
ALKALI SCRUBBING TEST FACILITY
DETROIT EDISON, ST. CLAIR PLANT, MICHIGAN

FLOW DIAGRAM
ADDITIVE SUPPLY SYSTEM

6955
Figure 3-2
0

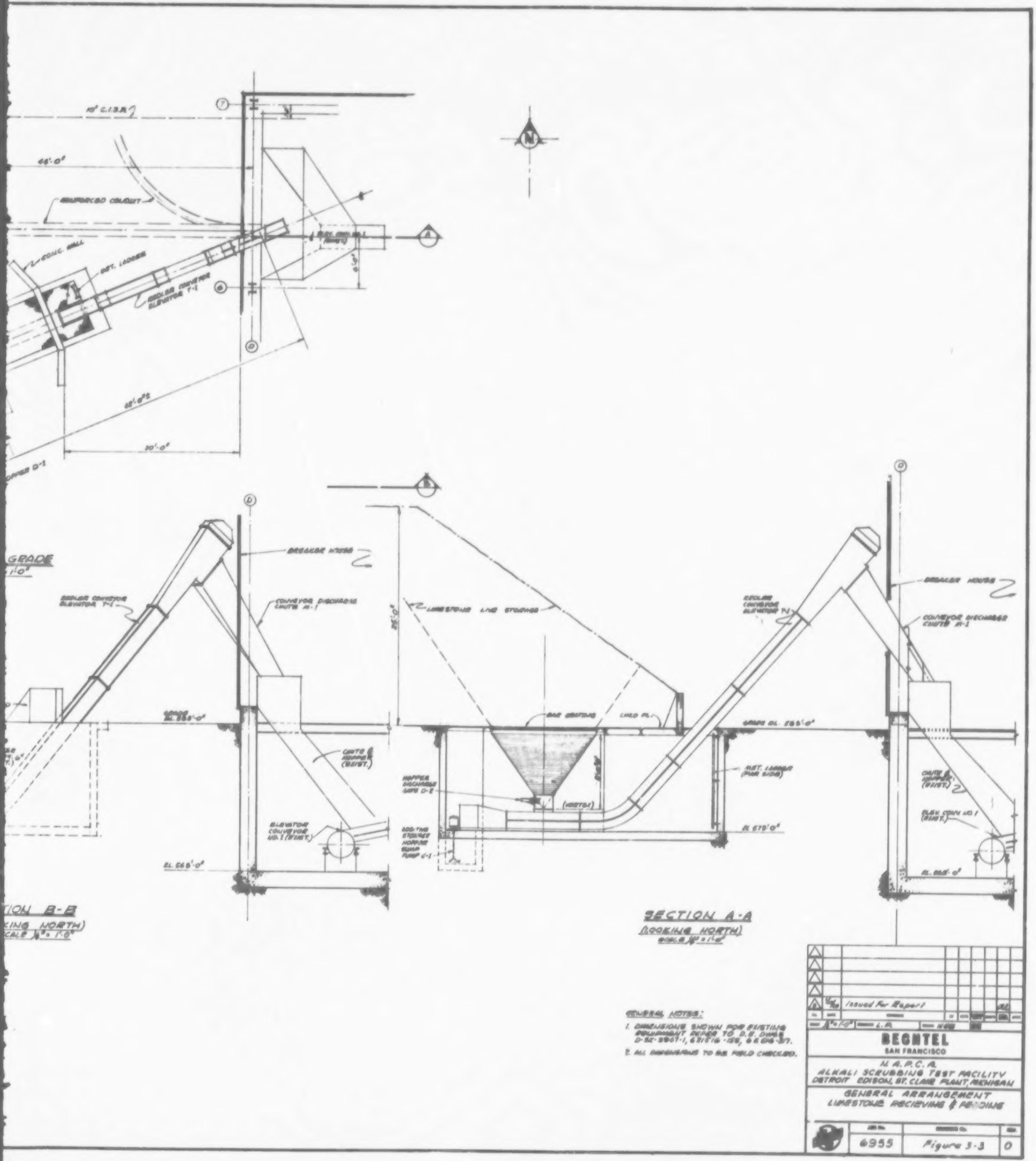
B


M.H. # 1 (EXIST.)
I.E. 580.5'
10" C.I.S.P.
44'-0"
REINFORCED CONDUIT
4" SEWER EL. 580'-0" (EXIST.)
CONC. WALL
MET. LADDER
ROLLER CONVEYOR ELEVATOR T-1
7
6
D
A
B
ADDITIVE HOPPER SUMP PUMP G-1-7
BAR GRATING
8'-0"
10'-0"
6'-0"
FEED HOPPER D-1
4" C.I. (EXIST.) SEE SECTION B-B
SEE SECTION B-B
48'-0"±
20'-0"
℄ PIPE
℄ FEED HOPPER D-1
℄ PIPE
EQUAL
EQUAL
CONC WALL BEYOND
GRADE EL. 588'-0"
4" SEWER EL. 580'-0" (EXIST.)
4" C.I. EL. 578'-10" (EXIST.)
6" WATER EL. 577'-6" (EXIST.)
BREAKER HOUSE
CONVEYOR DISCHARGE CHUTE M-1
25'-0"
LIMESTONE LINE
CHUTE & HOPPER (EXIST.)
HOPPER DISCHARGE GATE D-2
ELEVATOR CONVEYOR NO. 1 (EXIST.)
EXISTING STORAGE HOPPER SUMP PUMP G-1
EL. 563'-0"

PLAN ABOVE GRADE
SCALE 1/8" = 1'-0"

SECTION B-B
(LOOKING NORTH)
SCALE 1/8" = 1'-0"

A



15' C.I.S.P.
44'-0"
REINFORCED CONDUIT
2-CONC. WALL
RET. LADDER
REDLER CONVEYOR ELEVATOR T-1
ELEV. CONV. NO. 1 (EXIST.)
6'-0"
65'-0"±
30'-0"
HOPPER D-1
N
A
B
7
6
D
GRADE
BREAKER HOUSE
REDLER CONVEYOR ELEVATOR T-1
CONVEYOR DISCHARGE CHUTE H-1
LIMESTONE LIVE STORAGE
25'-0"
GRADE EL. 585'-0"
CHUTE & HOPPER (EXIST.)
ELEVATOR CONVEYOR NO. 1 (EXIST.)
EL. 565'-0"
TION B-B
KING NORTH)
CALE 1/8" = 1'-0"
BAR GRATING
CHKD PL.
HOPPER DISCHARGE GATE D-2
ADDITIVE STORAGE HOPPER SUMP PUMP C-1
(HOSTEL)
GRADE EL. 585'-0"
RET. LADDER (FAR SIDE)
EL. 575'-0"
REDLER CONVEYOR ELEVATOR T-1
BREAKER HOUSE
CONVEYOR DISCHARGE CHUTE H-1
CHUTE & HOPPER (EXIST.)
ELEV. CONV. NO. 1 (EXIST.)
EL. 565'-0"
SECTION A-A
(LOOKING NORTH)
SCALE 1/8" = 1'-0"
GENERAL NOTES:
1. DIMENSIONS SHOWN FOR EXISTING EQUIPMENT REFER TO D.E. DWGS. D-52-3967-1, 631516-156, 6 E 616-3?7.
2. ALL DIMENSIONS TO BE FIELD CHECKED.
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1/8" = 1'-0"
L.A.
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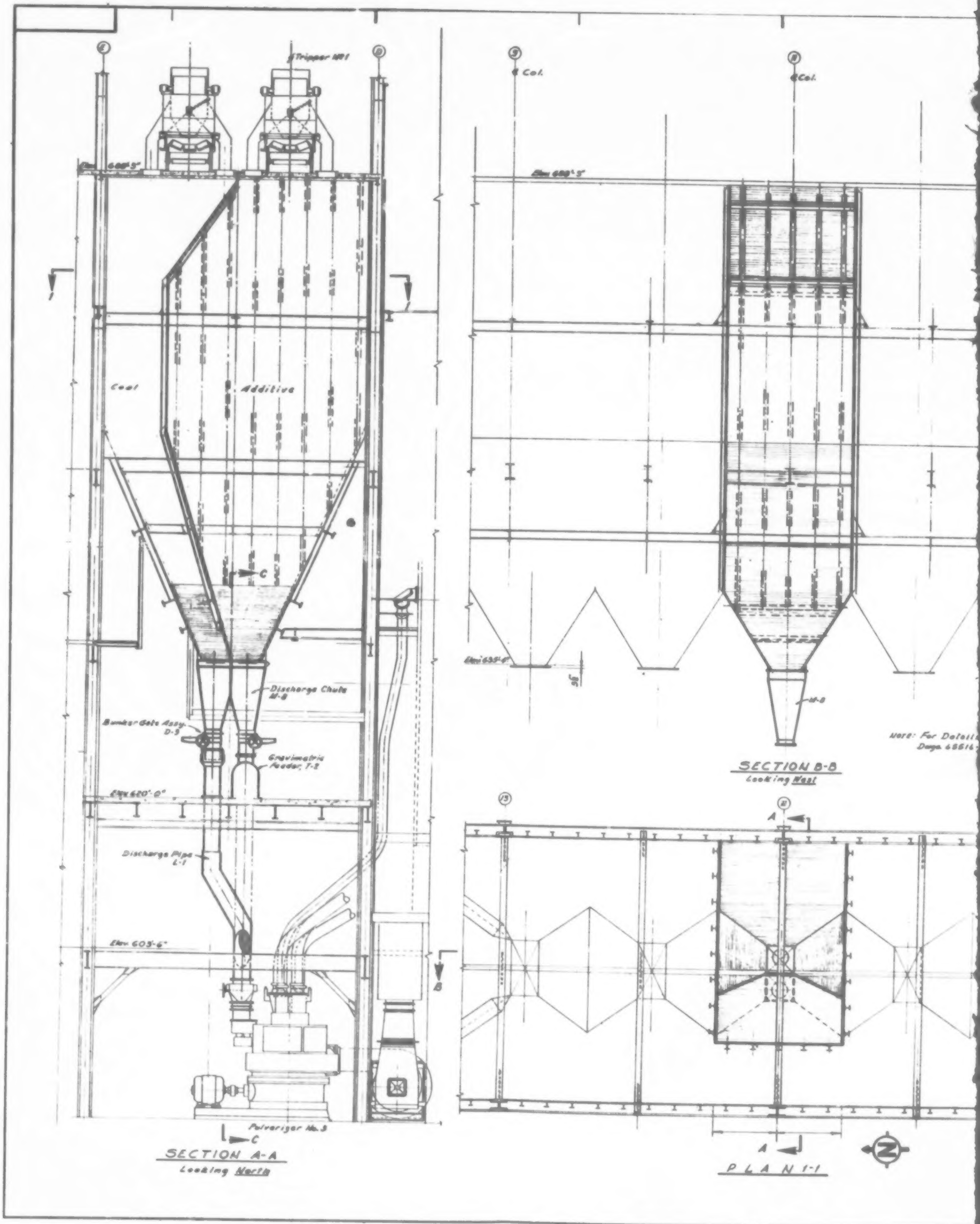
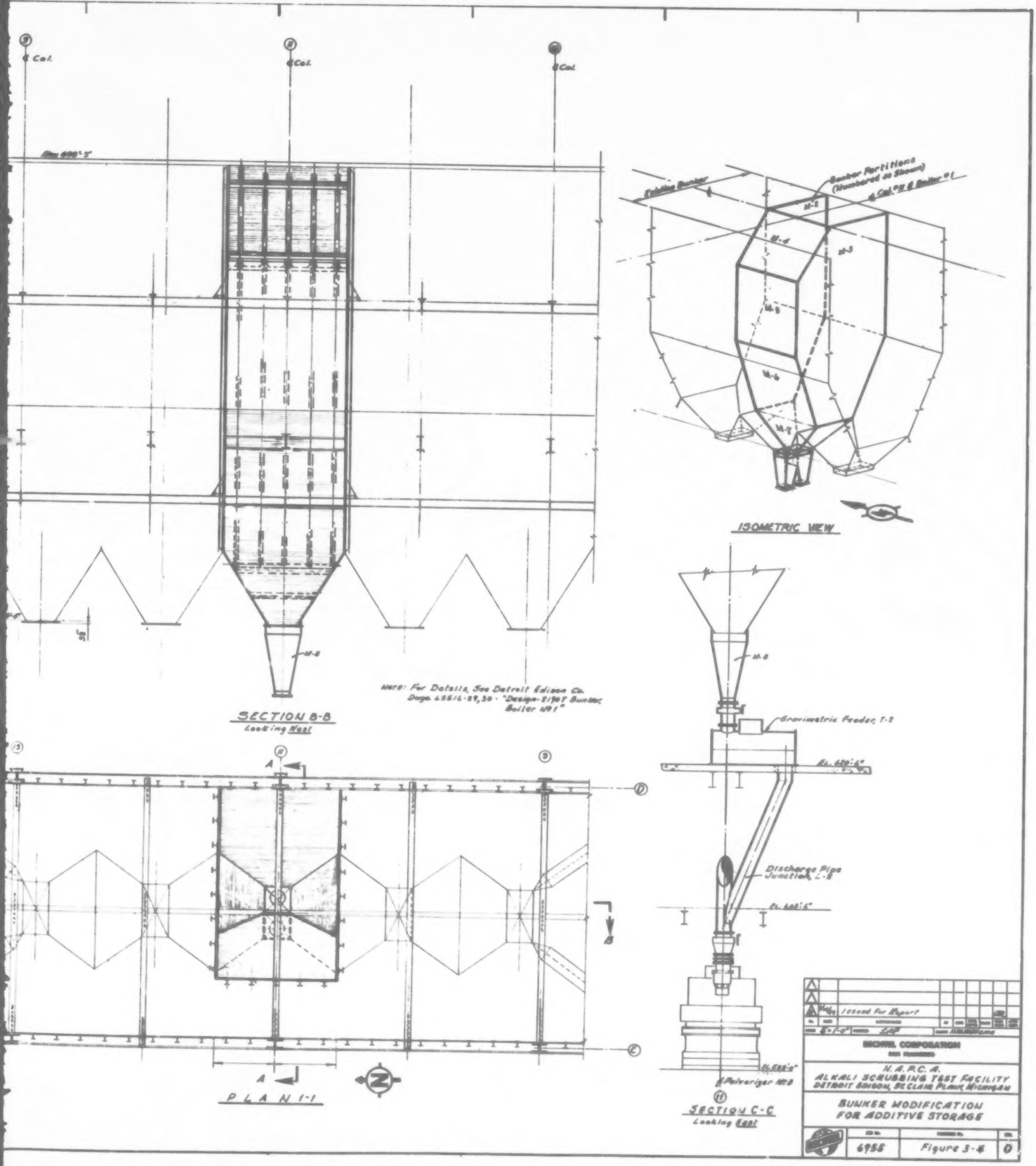
DETROIT EDISON, ST. CLAIR PLANT, MICHIGAN
GENERAL ARRANGEMENT
LIMESTONE RECIEVING & FEEDING
6955
Figure 3-3
0

B


Tripper No 1
Elev 668'-5"
Coal
Additive
C
Discharge Chute M-8
Bunker Gate Assy. D-9
Gravimetric Feeder, T-2
Elev 620'-0"
Discharge Pipe L-1
Elev 605'-6"
B
Pulverizer No. 3
C
SECTION A-A
Looking North
9
℄ Col.
11
℄ Col.
Elev 668'-5"
Elev 635'-6"
M-8
Note: For Detail
Dwgs. 48816-
SECTION B-B
Looking West
13
11
A
A
PLAN 1-1
N

A


℄ Col.
℄ Col.
℄ Col.
SECTION B-B
Looking West
M-8
Note: For Details, See Detroit Edison Co. Dwgs. 65516-29,30 - "Design-2190T Bunker, Boiler No1"
Existing Bunker
Bunker Partitions (Numbered as Shown)
℄ Col. 11 & Boiler #1
M-2
M-4
M-3
M-5
M-6
M-7
ISOMETRIC VIEW
Gravimetric Feeder, F-2
Discharge Pipe Junction, L-8
Pulverizer No.8
SECTION C-C
Looking East
A
A
B
D
E
PLAN 1-1
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BECHTEL CORPORATION
SAN FRANCISCO
N.A.P.C.A.
ALKALI SCRUBBING TEST FACILITY
DETROIT EDISON, ST. CLAIR PLANT, MICHIGAN
BUNKER MODIFICATION FOR ADDITIVE STORAGE
6955
Figure 3-4
0

B

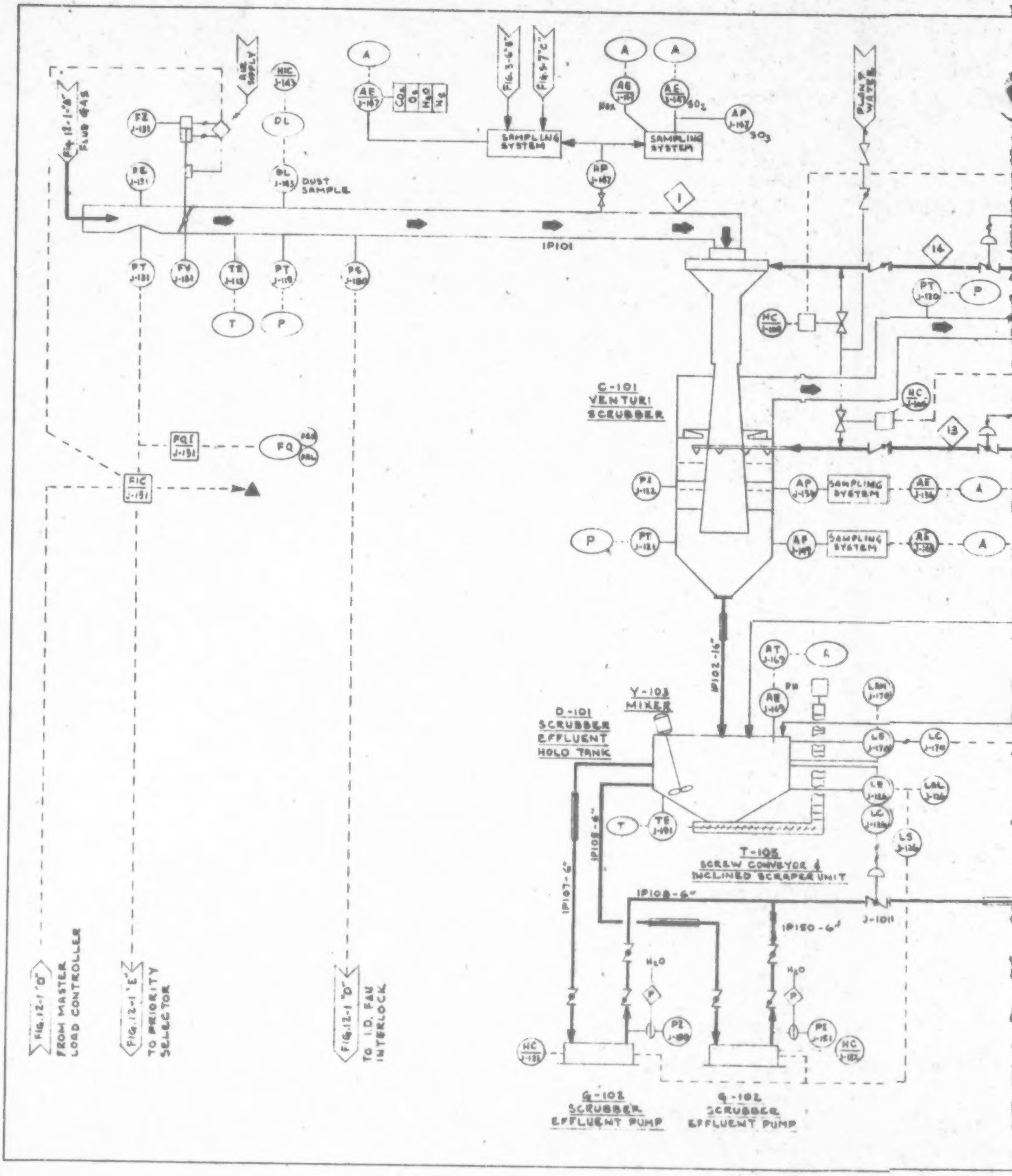
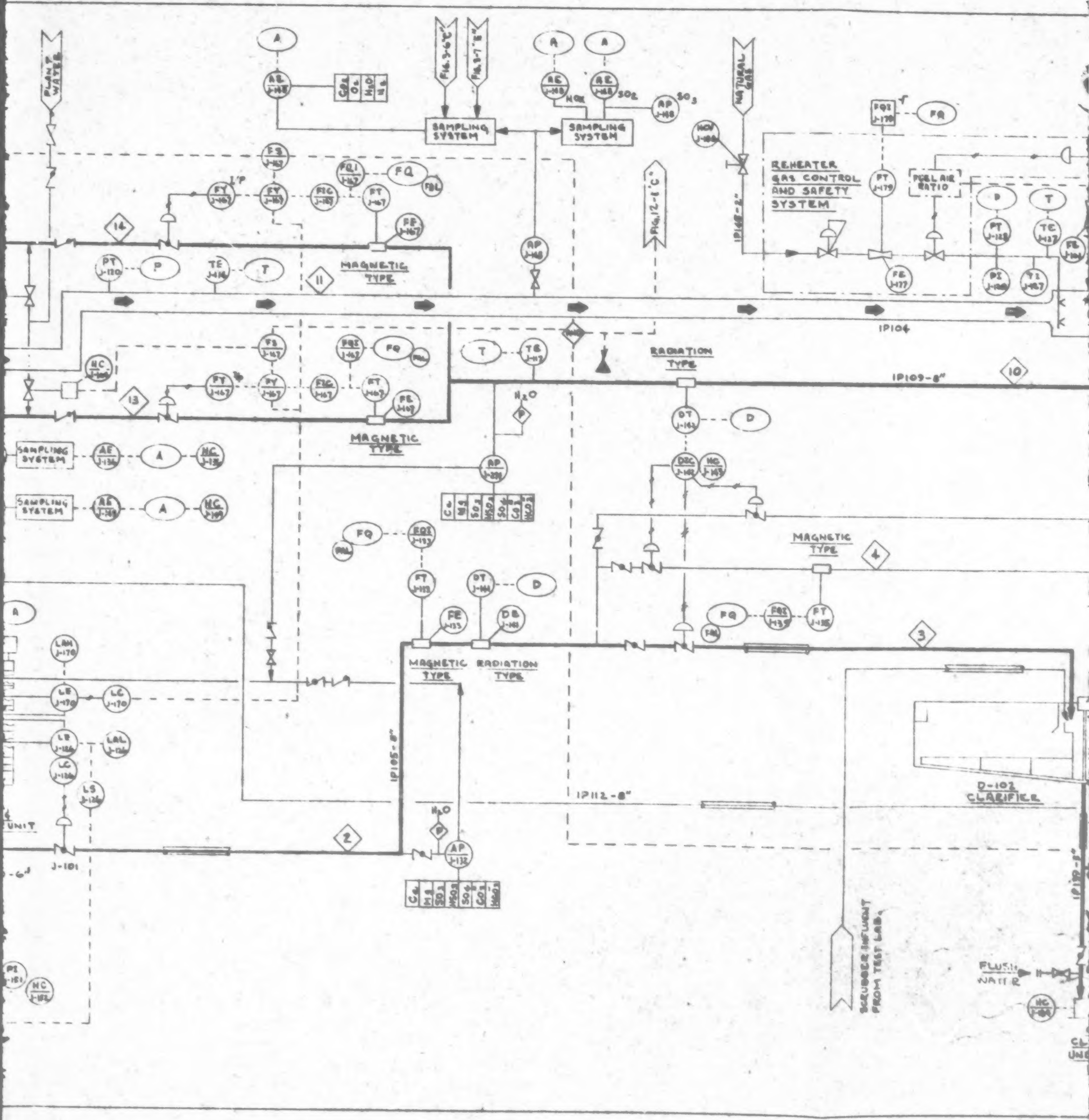
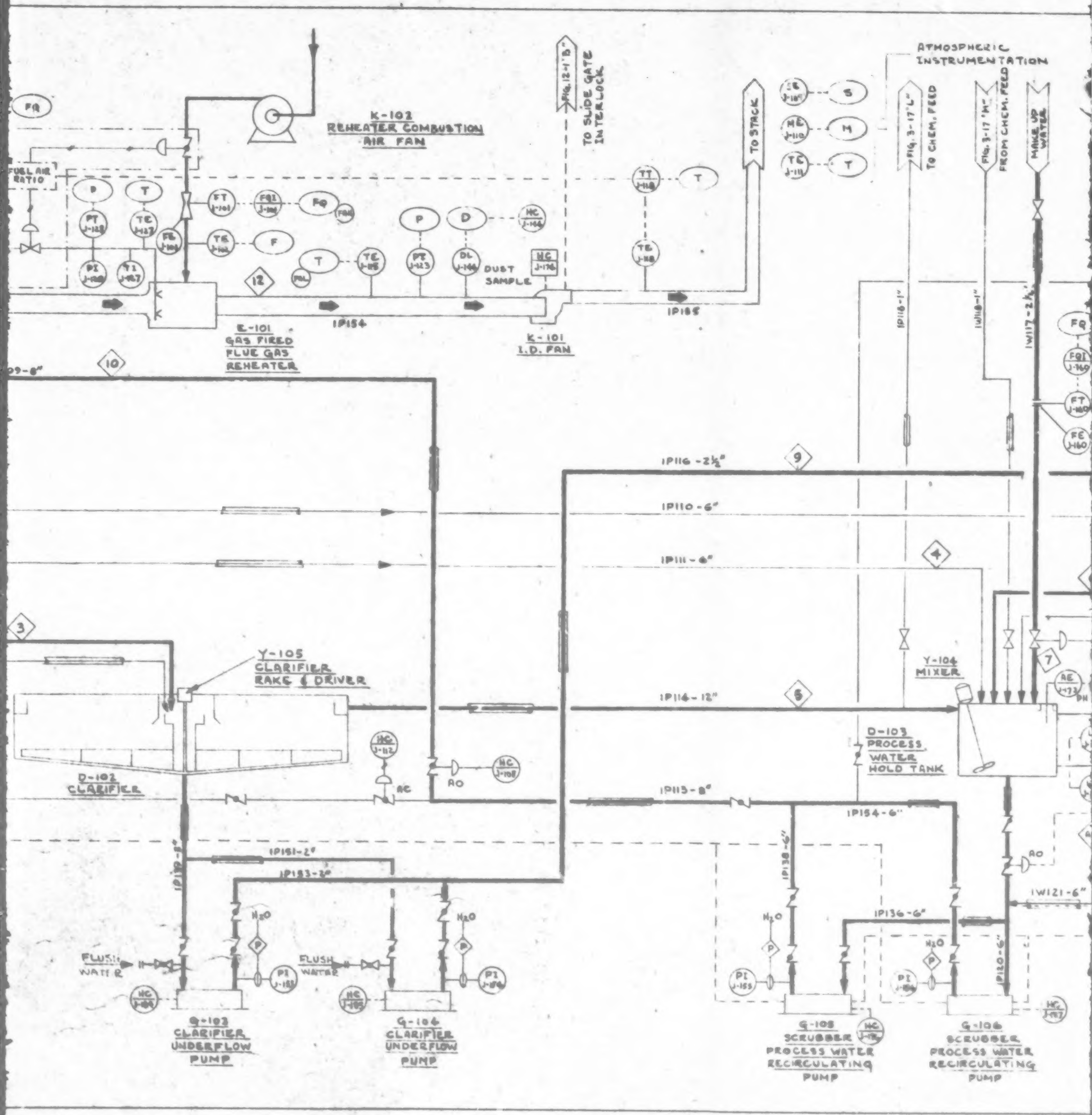


FIG. 12-1 "A" FLUE GAS
AIR SUPPLY
FZ J-131
FE J-131
PT J-131
FV J-131
HIC J-143
DL
DL J-143 DUST SAMPLE
TE J-118
PT J-119
PS J-180
T
P
A
AE J-147
CO_2
O_2
H_2O
N_2
FIG. 3-6 "B"
FIG. 5-7 "C"
SAMPLING SYSTEM
A
A
AE J-147 NOx
AE J-147 SO_2
AP J-147 SO_3
SAMPLING SYSTEM
AP J-147
1
1P101
PLANT WATER
14
PT J-120
P
HC J-108
HC J-109
13
C-101 VENTURI SCRUBBER
PI J-122
AP J-136
SAMPLING SYSTEM
AE J-136
A
P
PT J-121
AP J-149
SAMPLING SYSTEM
AE J-136
A
FQI J-131
FQ
FIC J-131
1P102-16"
AT J-169
A
AE J-169 PH
LAH J-170
LE J-170
LC J-170
LE J-126
LAL J-126
LC J-126
LS J-126
Y-103 MIXER
D-101 SCRUBBER EFFLUENT HOLD TANK
T
TE J-101
T-105 SCREW CONVEYOR & INCLINED SCRAPER UNIT
1P108-6"
1P107-6"
1P106-6"
1P150-6"
J-1011
H_2O
P
PI J-180
H_2O
P
PI J-151
HC J-181
HC J-182
G-102 SCRUBBER EFFLUENT PUMP
G-102 SCRUBBER EFFLUENT PUMP
FIG. 12-1 "D" FROM MASTER LOAD CONTROLLER
FIG. 12-1 "E" TO PRIORITY SELECTOR
FIG. 12-1 "D" TO I.D. FAN INTERLOCK

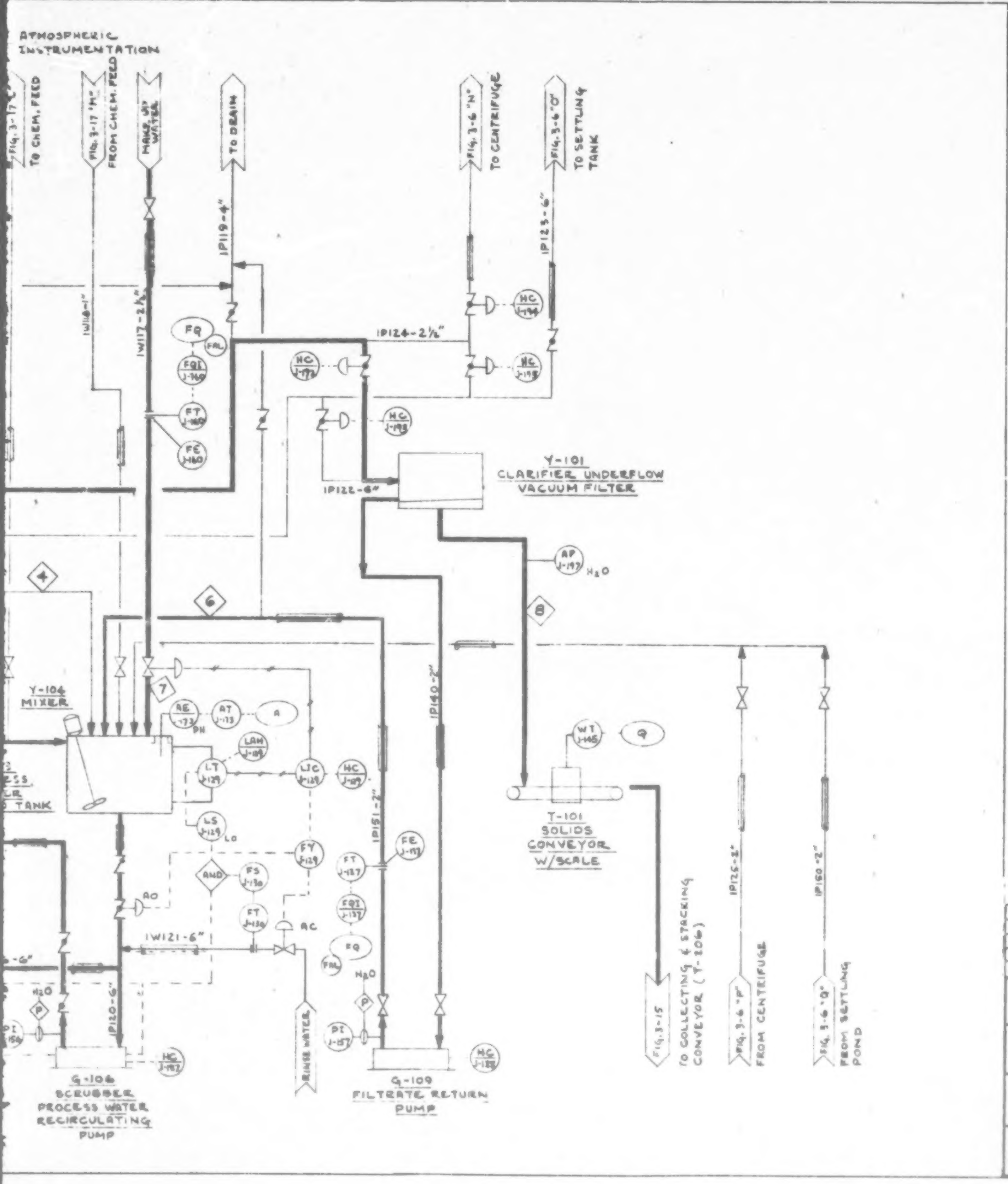
A


PLANT WATER
FIG. 3-6 "C"
FIG. 3-7 "E"
SAMPLING SYSTEM
SAMPLING SYSTEM
NATURAL GAS
NOX
SO2
SO3
CO2 O2 H2O N2
REHEATER GAS CONTROL AND SAFETY SYSTEM
FUEL AIR RATIO
FIG. 12-6 "C"
1P148-2"
1P104
MAGNETIC TYPE
MAGNETIC TYPE
RADIATION TYPE
1P109-8"
H2O
SAMPLING SYSTEM
SAMPLING SYSTEM
MAGNETIC TYPE
MAGNETIC TYPE
RADIATION TYPE
1P105-8"
1P112-8"
D-102 CLARIFIER
SCRUBBER INFLUENT FROM TEST LAB.
FLUSH WATER
UNIT
J-101
Cu Mg SO3 HSO3 SO4 CO3 HCO3
14
11
13
10
4
3
2
A
P
T
D
FQ
AE J-148
AP J-148
FS J-167
FY J-167
FIC J-167
FQI J-167
FT J-167
FE J-167
PT J-120
TE J-116
TE J-117
HC J-106
AE J-136
HC J-136
AE J-149
HC J-149
AP J-231
FQI J-133
FT J-133
FE J-133
DT J-144
DE J-141
AP J-132
DT J-142
DIC J-142
HC J-143
FQI J-135
FT J-135
HCV J-180
FQI J-178
PT J-179
FE J-177
PT J-128
TE J-127
DI J-128
TI J-127
LAH J-170
LE J-170
LC J-170
LE J-126
LAL J-126
LC J-126
LS J-126
PI J-151
HC J-152

B


FR
FUEL AIR RATIO
K-102
REHEATER COMBUSTION AIR FAN
P
T
PT J-128
TE J-127
PI J-128
TI J-127
FE J-101
FT J-101
FQI J-101
FQ
TE J-102
F
T
TE J-125
P
PT J-123
D
DL J-144
HC J-144
DUST SAMPLE
HC J-176
12
1P154
E-101
GAS FIRED FLUE GAS REHEATER
K-101
I.D. FAN
FIG. 12-1 "B"
TO SLIDE GATE INTERLOCK
TT J-118
TE J-118
T
TO STACK
1P155
SE J-109
S
ME J-110
M
TE J-111
T
ATMOSPHERIC INSTRUMENTATION
FIG. 3-17 "L"
TO CHEM. FEED
FIG. 3-17 "M"
FROM CHEM. FEED
MAKE UP WATER
1P118-1"
1W118-1"
1W117-2½"
FQ
FQI J-160
FT J-160
FE J-160
09-8"
10
1P116-2½"
9
1P110-6"
1P111-6"
4
3
Y-105
CLARIFIER RAKE & DRIVER
1P114-12"
5
D-102
CLARIFIER
HC J-112
AC
HC J-108
AO
1P115-8"
D-103
PROCESS WATER HOLD TANK
Y-104
MIXER
7
AE J-173
PH
1P154-6"
1P130-8"
1P151-2"
1P153-2"
H2O
P
PI J-153
PI J-154
FLUSH WATER
HC J-104
HC J-105
G-103
CLARIFIER UNDERFLOW PUMP
G-104
CLARIFIER UNDERFLOW PUMP
1P138-6"
1P136-6"
1P120-6"
AO
1W121-6"
PI J-155
PI J-156
HC J-116
HC J-117
G-105
SCRUBBER PROCESS WATER RECIRCULATING PUMP
G-106
SCRUBBER PROCESS WATER RECIRCULATING PUMP

C


ATMOSPHERIC INSTRUMENTATION
FIG. 3-17 "
TO CHEM. FEED
FIG. 3-17 "H"
FROM CHEM. FEED
MAKE UP WATER
TO DRAIN
FIG. 3-6 "N"
TO CENTRIFUGE
FIG. 3-6 "O"
TO SETTLING TANK
1W118-1"
1W117-2½"
1P119-4"
1P123-6"
1P124-2½"
FQ
FAL
FQI J-160
FT J-160
FE J-160
HC J-194
HC J-195
HC J-192
HC J-193
Y-101
CLARIFIER UNDERFLOW VACUUM FILTER
1P122-6"
AP J-197
H₂O
4
6
8
7
Y-104
MIXER
AE J-173
PH
AT J-173
A
LAH J-129
LT J-129
LIC J-129
HC J-129
LS J-129
LO
FY J-129
AND
FS J-130
FT J-130
AO
AC
1W121-6"
RINSE WATER
1P151-2"
1P140-2"
FT J-137
FE J-137
FQI J-137
FQ
FAL
H₂O
P
PI J-157
PI J-156
HC J-128
HC J-187
1P120-6"
G-106
SCRUBBER PROCESS WATER RECIRCULATING PUMP
G-109
FILTRATE RETURN PUMP
WT J-145
Q
T-101
SOLIDS CONVEYOR W/SCALE
FIG. 3-15
TO COLLECTING & STACKING CONVEYOR (T-206)
1P125-2"
FIG. 3-6 "P"
FROM CENTRIFUGE
1P160-2"
FIG. 3-6 "Q"
FROM SETTLING POND
SS
LR
TANK
-6"

1. ◇P = INDICAT
2. AP = INDICAT
3. FOR INSTRUM
IDENTIFICAT
APPENDIX E
4. SYMBOLS BEL
IDENTIFICATI

⊟ DEVICE
BOILER

⊖ DEVICE
TEST FA

○ LOCAL

SCALE NONE

BECHT

ALKALIS
DETOIT EDIS

PROCESS PIPI

D

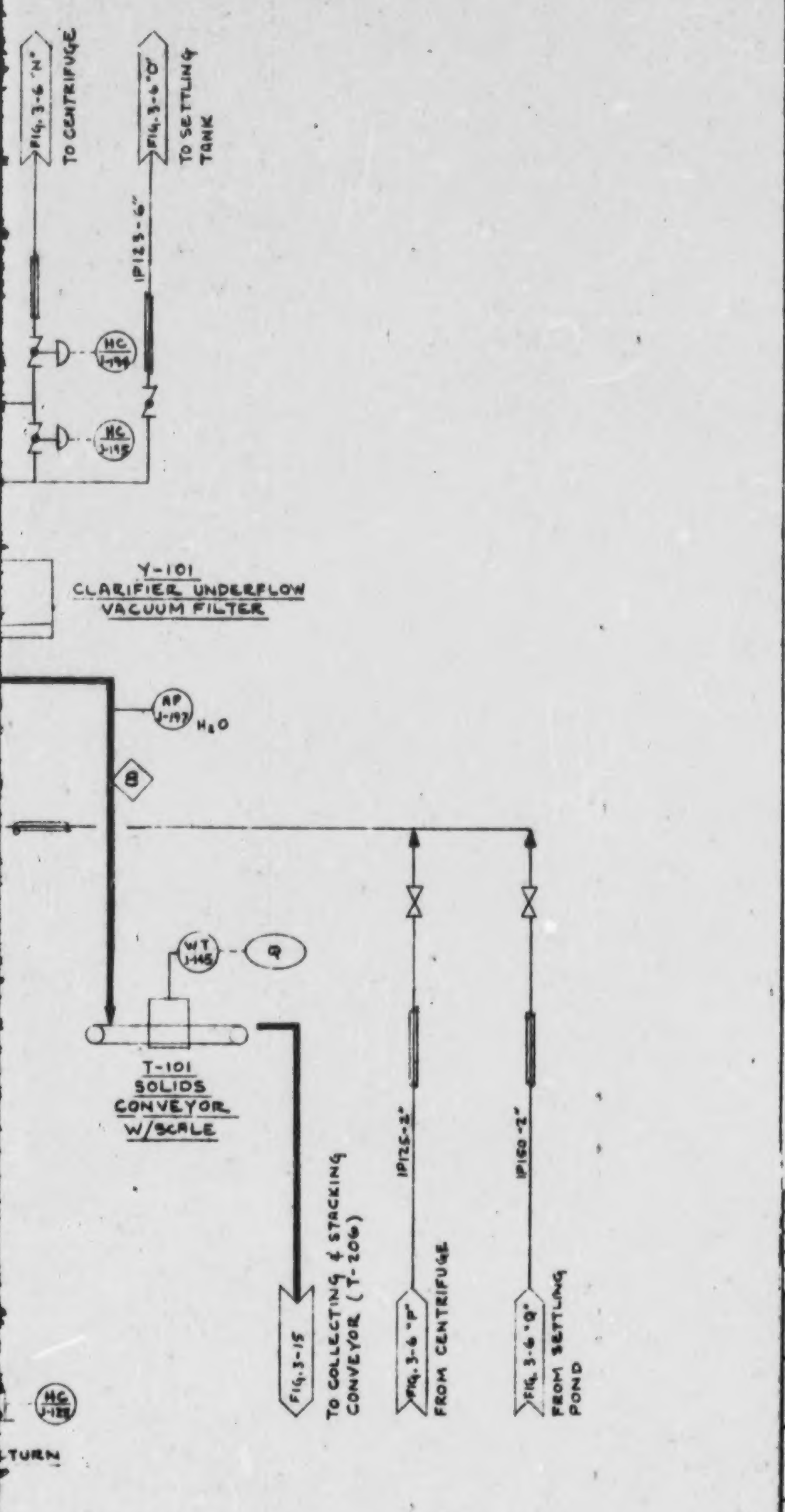


FIG. 3-6 "N"
TO CENTRIFUGE
FIG. 3-6 "O"
TO SETTLING TANK
1P123-6"
HC 1-194
HC 1-195
Y-101
CLARIFIER UNDERFLOW
VACUUM FILTER
AP 1-197
H₂O
8
WT 1-145
Q
T-101
SOLIDS
CONVEYOR
W/SCALE
FIG. 3-15
TO COLLECTING & STACKING CONVEYOR (T-206)
1P125-2"
FIG. 3-6 "P"
FROM CENTRIFUGE
1P150-2"
FIG. 3-6 "Q"
FROM SETTLING POND
HC 1-128
TURN

NOTES.

1. ⟨P⟩ = INDICATE PURGE POINT
2. AP = INDICATE SAMPLE POINT
3. FOR INSTRUMENTATION NUMBERING & IDENTIFICATION, REFERENCE APPENDIX E-1, E-2, E-3, E-4 & E-5
4. SYMBOLS BELOW CARRY THE IDENTIFICATION INDICATED

⊟ DEVICE LOCATED IN BOILER CONTROL ROOM

⊖ DEVICE LOCATED IN TEST FACILITY CONTROL CENTER

○ LOCAL MOUNTED DEVICES

△								
△								
△	[illegible]	ISSUED FOR REPORT				[illegible]		
NO.	DATE	REVISIONS	BY					

SCALE NONE
DRAWN J. HING

BECHTEL CORPORATION
SAN FRANCISCO

N. A. P. C. A.
ALKALI SCRUBBING TEST FACILITY
DETOIT EDISON ST. CLAIR PLANT-MICHIGAN

PROCESS PIPING & INSTRUMENTATION DIAGRAM
PLANT NO. 100

JOB NO.	DRAWING NO.	REV.
6955	FIGURE 3-5	0

E

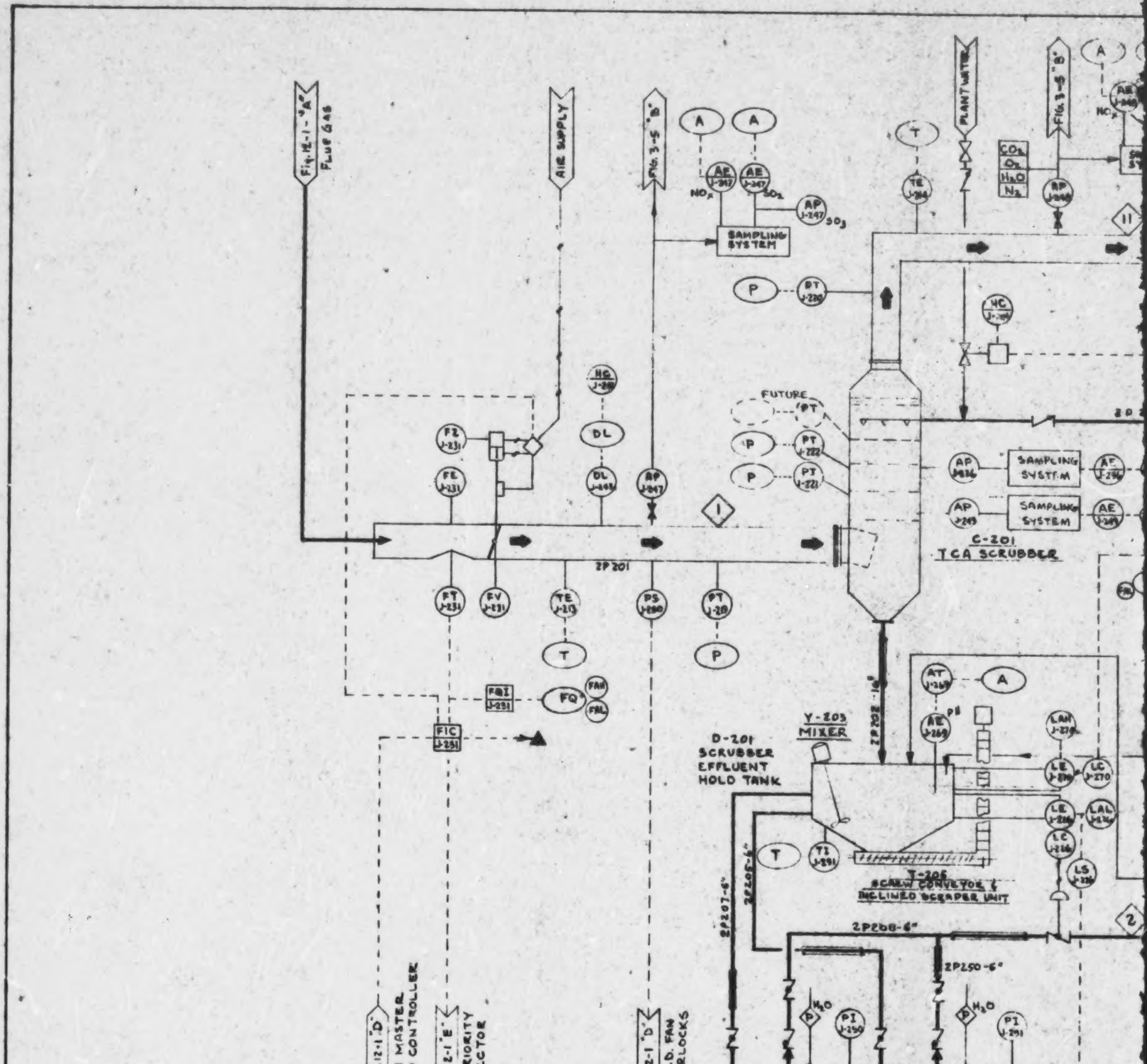


Fig. 12-1 "A"
FLUE GAS
AIR SUPPLY
FIG. 3-5 "B"
A
A
AE J-247
NOx
AE J-247
SO2
AP J-247
SO3
SAMPLING SYSTEM
P
PT J-220
T
TE J-264
PLANT WATER
FIG. 3-5 "B"
A
AE J-248
NOx
CO2
O2
H2O
N2
AP J-248
11
HC J-261
HC J-241
DL
DL J-249
FUTURE
PT
P
PT J-222
P
PT J-221
FZ J-231
FE J-231
AP J-247
1
AP J-246
SAMPLING SYSTEM
AE J-246
AP J-249
SAMPLING SYSTEM
AE J-249
2P 201
C-201
TCA SCRUBBER
FT J-231
FV J-231
TE J-213
PS J-290
PT J-211
T
P
FQI J-231
FQ
FAH
FAL
FIC J-231
AT J-269
A
AE J-269
pH
Y-203
MIXER
2P202-16"
D-201
SCRUBBER EFFLUENT HOLD TANK
LAH J-270
LE J-270
LC J-270
LE J-226
LAL J-226
LC J-226
LS J-226
T
TI J-291
T-206
SCREW CONVEYOR & INCLINED SCRAPER UNIT
2P207-6"
2P205-6"
2P208-6"
2P250-6"
2
H2O
PI J-250
H2O
PI J-251
HC J-281
HC J-282
G-201
SCRUBBER EFFLUENT PUMP
G-202
SCRUBBER EFFLUENT PUMP
FIG. 12-1 "D"
FROM MASTER LOAD CONTROLLER
FIG. 12-1 "E"
TO PRIORITY SELECTOR
FIG. 12-1 "D"
TO I.D. FAN INTERLOCKS

A

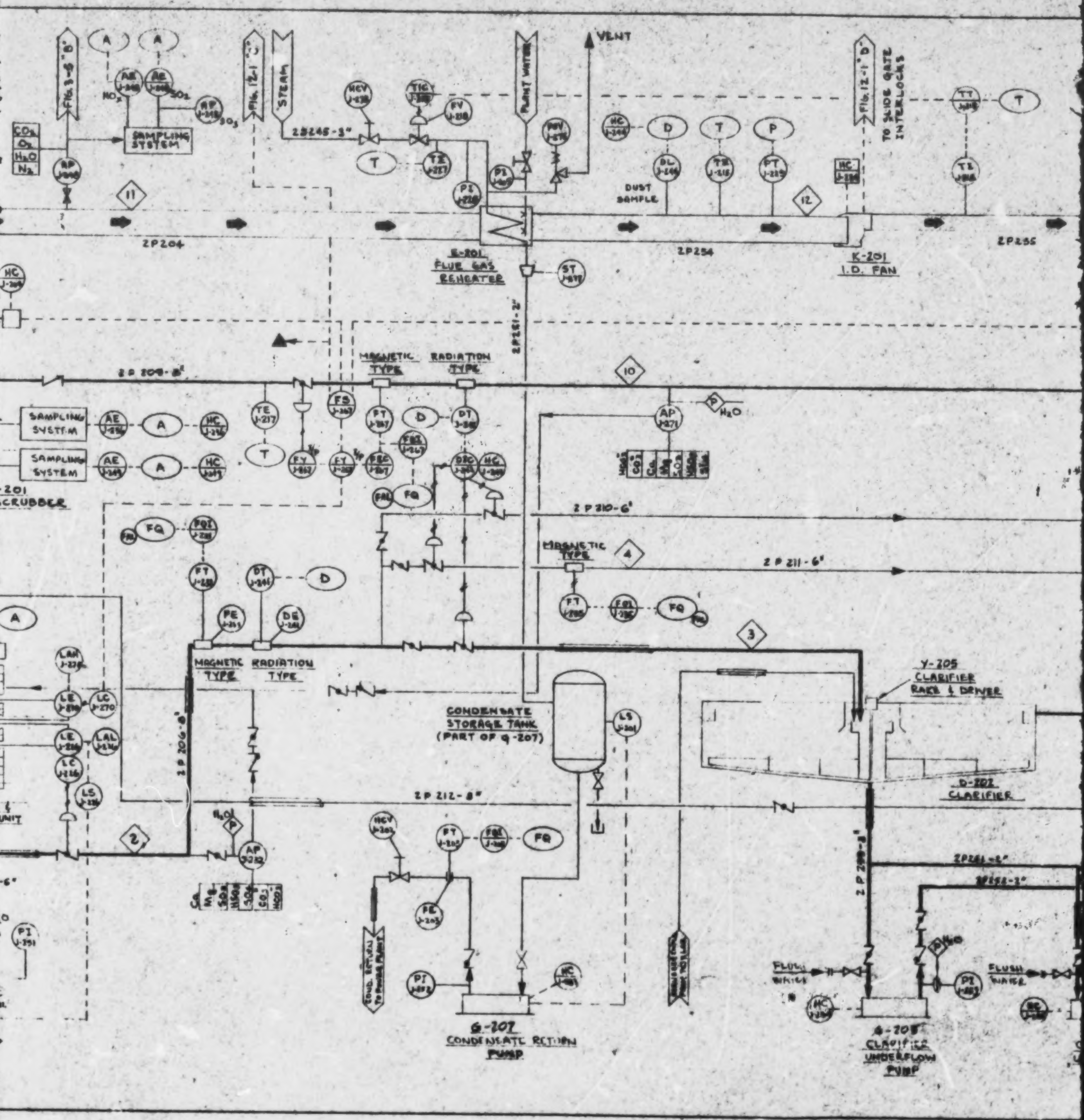
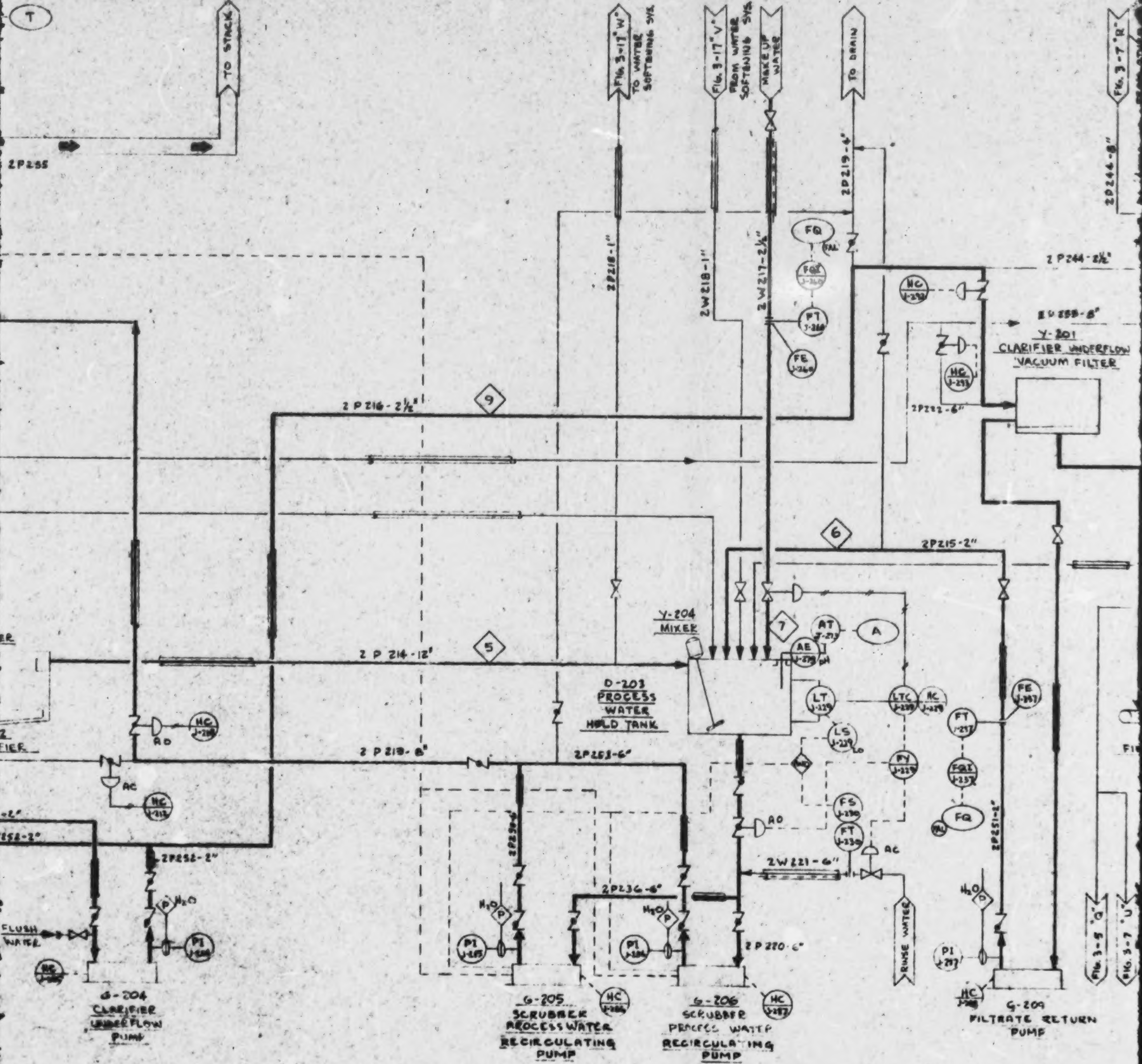


Fig. 3-5 "B"
A
A
AE
AE
NO$_x$
SO$_2$
AP J-218
SO$_3$
CO$_2$
O$_2$
H$_2$O
N$_2$
SAMPLING SYSTEM
AP
Fig. 12-1 "C"
STEAM
2S245-3"
HCV
TIC
FV J-218
T
TE J-217
PI
PI J-220
PLANT WATER
PCV
VENT
11
2P204
E-201
FLUE GAS
REHEATER
ST
2P261-2"
HC
D
T
P
DL
TE J-215
PT J-225
DUST SAMPLE
12
HC
Fig. 12-1 "D"
TO SLIDE GATE INTERLOCKS
TT
T
TE
2P254
K-201
I.D. FAN
2P255
HC
2P 209-8"
MAGNETIC TYPE
RADIATION TYPE
10
SAMPLING SYSTEM
AE
A
HC
SAMPLING SYSTEM
AE
A
HC
-201
SCRUBBER
TE J-217
T
FY
FS
FY
FT
D
DT
FQI
FQC
DRC
HC
FAL
FQ
AP J-271
P
H$_2$O
2P 210-6"
MAGNETIC TYPE
4
2P 211-6"
FQ
FQI
FT
DT
D
FT
FQ
FQI
A
PE
DE
MAGNETIC TYPE
RADIATION TYPE
3
LAH
LE
LC J-270
LE
LAL
LC
LS
UNIT
2P 206-8"
2
H$_2$O
P
AP
2P 212-8"
CONDENSATE STORAGE TANK
(PART OF G-207)
LS J-201
Y-205
CLARIFIER RAKE & DRIVER
D-202
CLARIFIER
HCV J-202
FT J-202
FQI
FQ
FE J-203
COND. RETURN TO POWER PLANT
PI
HC
G-207
CONDENSATE RETURN PUMP
2P 208-8"
2P261-2"
2P262-2"
FLUSH WATER
HC
P
H$_2$O
PI
FLUSH WATER
G-208
CLARIFIER UNDERFLOW PUMP
PI J-251
-6"

B


T
TO STACK
2P255
FIG. 3-17 "W" TO WATER SOFTENING SYS.
FIG. 3-17 "V" FROM WATER SOFTENING SYS.
MAKE UP WATER
TO DRAIN
FIG. 3-7 "R"
2P244-8"
2P218-1"
2W218-1"
2W217-2½"
2P219-4"
FQ
FAL
FQI J-260
PT J-260
FE J-260
2 P244-2½"
HC J-292
HC J-293
2P232-6"
Y-201
CLARIFIER UNDERFLOW VACUUM FILTER
9
2 P 216-2½"
6
2P215-2"
Y-204
MIXER
7
AT J-273
A
AE J-273
pH
5
2 P 214-12"
D-203
PROCESS WATER HOLD TANK
LT J-229
LTC J-229
AC J-229
LS J-229
LO
FY J-229
FS J-230
FT J-230
AC
AO
FE J-257
FT J-257
FQI J-257
FQ
FAL
2P251-2"
2W221-6"
RINSE WATER
2 P 220-6"
2 P 213-8"
2P253-6"
2P236-6"
2P234-6"
AO
HC J-218
AC
HC J-212
-2"
2P252-2"
2P252-2"
FLUSH WATER
HC J-209
H_2O
P
PI J-210
PI J-215
PI J-216
PI J-217
HC J-206
HC J-207
HC J-208
G-204
CLARIFIER UNDERFLOW PUMP
G-205
SCRUBBER PROCESS WATER RECIRCULATING PUMP
G-206
SCRUBBER PROCESS WATER RECIRCULATING PUMP
G-209
FILTRATE RETURN PUMP
FIG. 3-5 "Q"
FIG. 3-7 "U"
FI

C

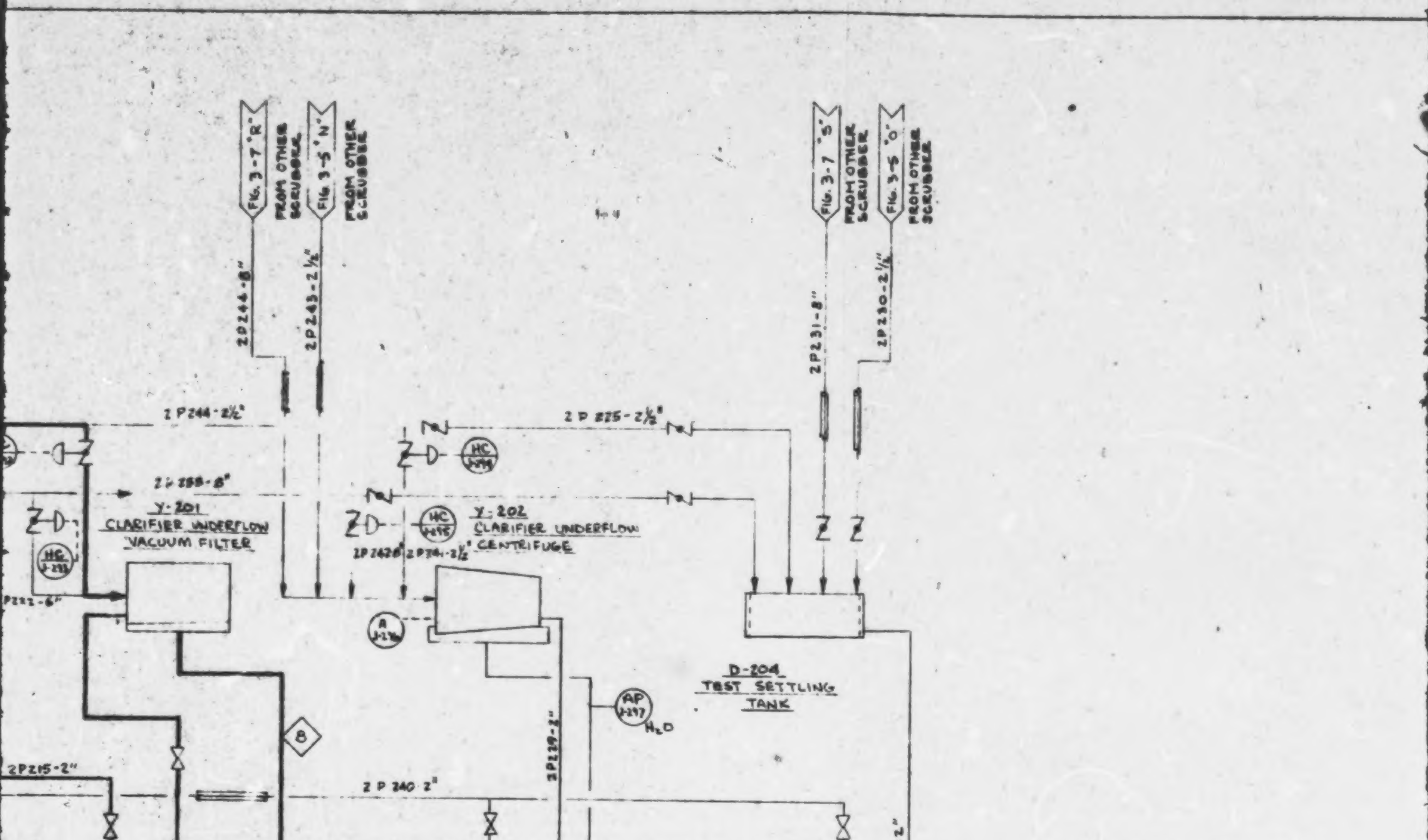


FIG. 3-7 'R' FROM OTHER SCRUBBER
FIG. 3-5 'N' FROM OTHER SCRUBBER
FIG. 3-7 'S' FROM OTHER SCRUBBER
FIG. 3-5 'O' FROM OTHER SCRUBBER
2P244-8"
2P243-2½"
2P231-8"
2P230-2½"
2P244-2½"
2P225-2½"
2P238-8"
HC J-294
HC J-295
HC J-293
Y-201 CLARIFIER UNDERFLOW VACUUM FILTER
Y-202 CLARIFIER UNDERFLOW CENTRIFUGE
2P242-8" 2P241-2½"
2P222-6"
A J-296
D-204 TEST SETTLING TANK
AP J-297 H₂O
8
2P215-2"
2P240-2"
2P239-2"
2P228-2"
2P232-2"
2P226-2"
2P251-2"
WT J-245
Q
WT J-246
Q
T-203 FILTER SOLIDS CONVEYOR W/SCALE
T-204 CENTRIFUGE SOLIDS CONVEYOR W/SCALE
HC J-259
FE J-237
FT J-237
FQI J-237
FQ
FQ
FQI J-238
FE J-238
FT J-238
FQ
FQI J-239
FE J-239
FT J-239
H₂O P
PI J-237
PI J-238
PI J-239
HC J-258
HC J-289
HC J-290
FIG. 3-5 'Q'
FIG. 3-7 'U'
PROCESS WATER HOLD TANK
FIG. 3-5 'P'
FIG. 3-7 'T'
PROCESS WATER HOLD TANK
TO SOLIDS STORAGE AREA
TO COLLECTING STACKING CONVEYOR (T-206)
FIG. 3-15
G-209 FILTRATE RETURN PUMP
G-210 CENTRATE RETURN PUMP
G-208 SETTLING TANK RECIRCULATION PUMP
NOT
FOR

D

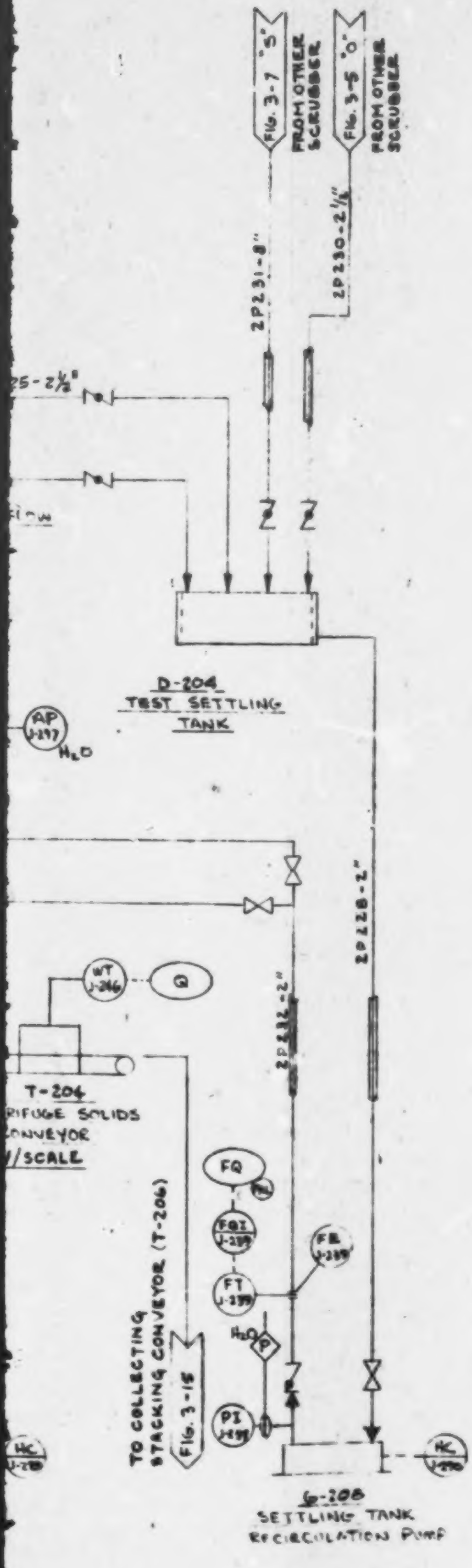


FIG. 3-7 "S"
FROM OTHER SCRUBBER
FIG. 3-5 "O"
FROM OTHER SCRUBBER
2P231-8"
2P230-2½"
25-2½"
FLOW
D-204
TEST SETTLING TANK
AP
J-297
H₂O
2P228-2"
2P232-2"
WT
J-246
Q
T-204
RIFUGE SOLIDS
CONVEYOR
W/SCALE
FQ
FQI
J-299
FT
J-299
FR
J-299
H₂O
P
PI
J-498
TO COLLECTING
STACKING CONVEYOR (T-206)
FIG. 3-15
HC
J-290
G-208
SETTLING TANK
RECIRCULATION PUMP

NOTE:
FOR GENERAL NOTES SEE FIGURE 3-5

Δ							
Δ							
0		ISSUED FOR ...					

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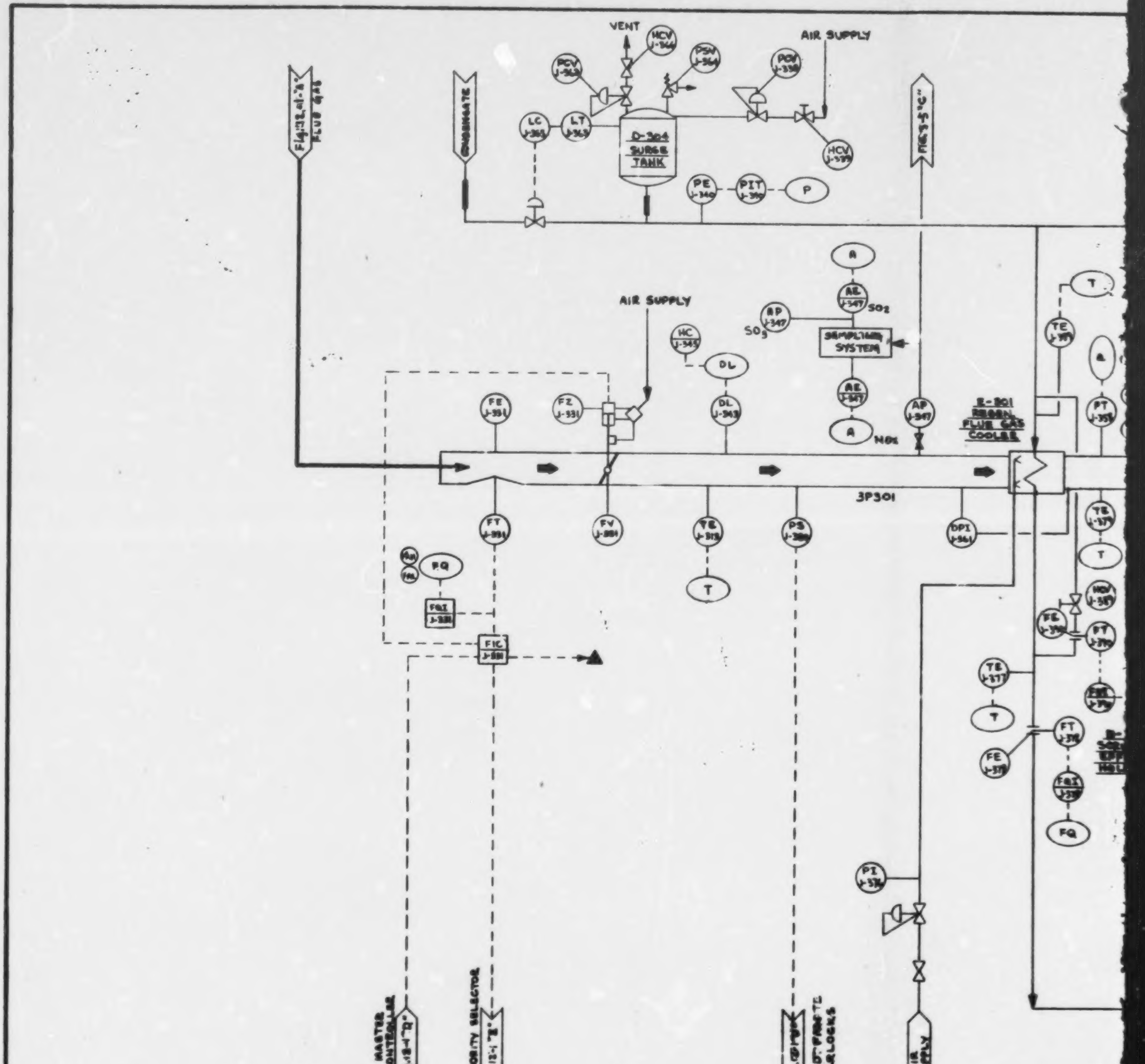
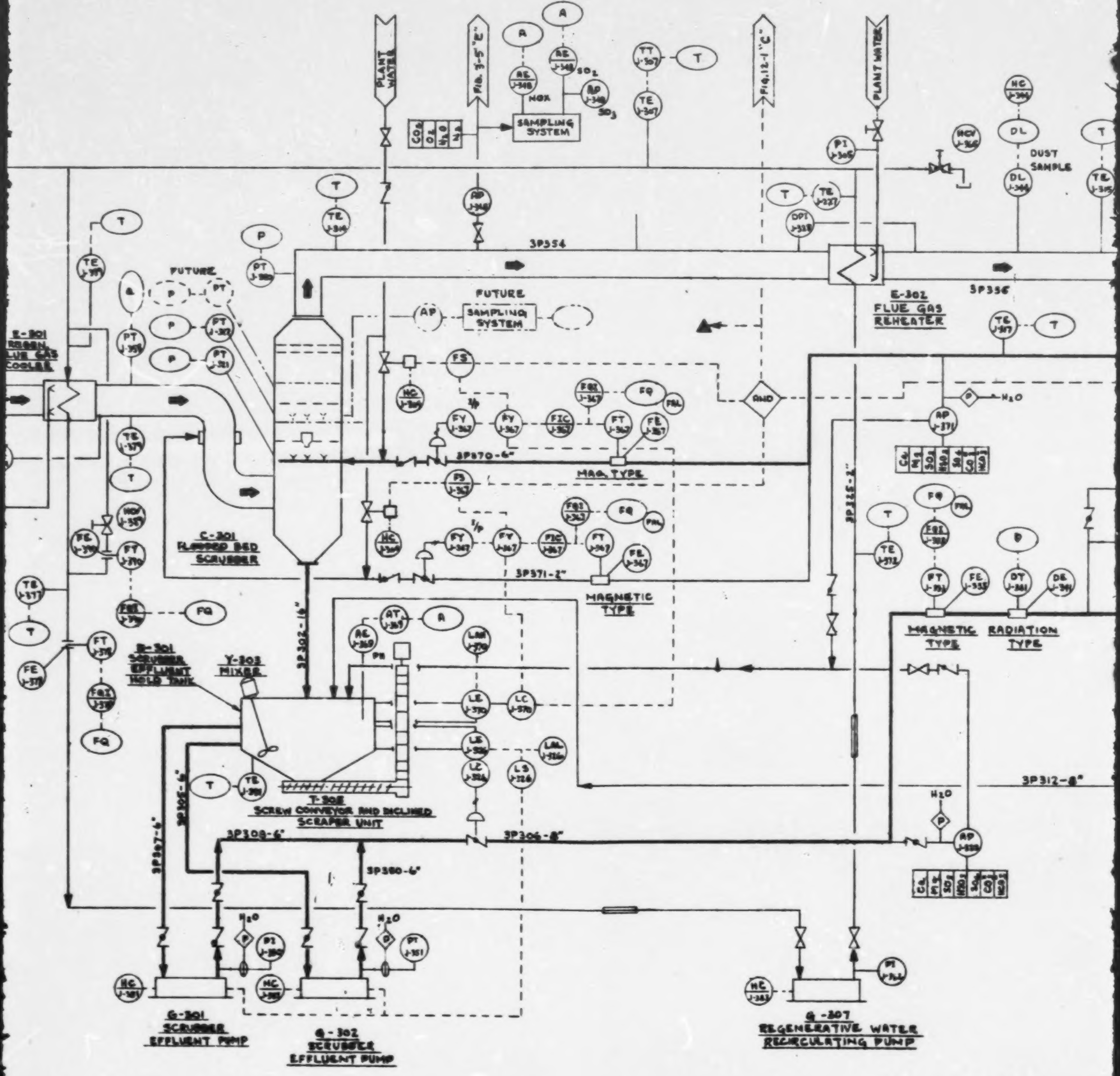
PROCESS PIPING & INSTRUMENTATION DIAGRAM
PLANT NO. 200

JOB No.	DRAWING No.	REV.
6955	FIGURE 3-6	0

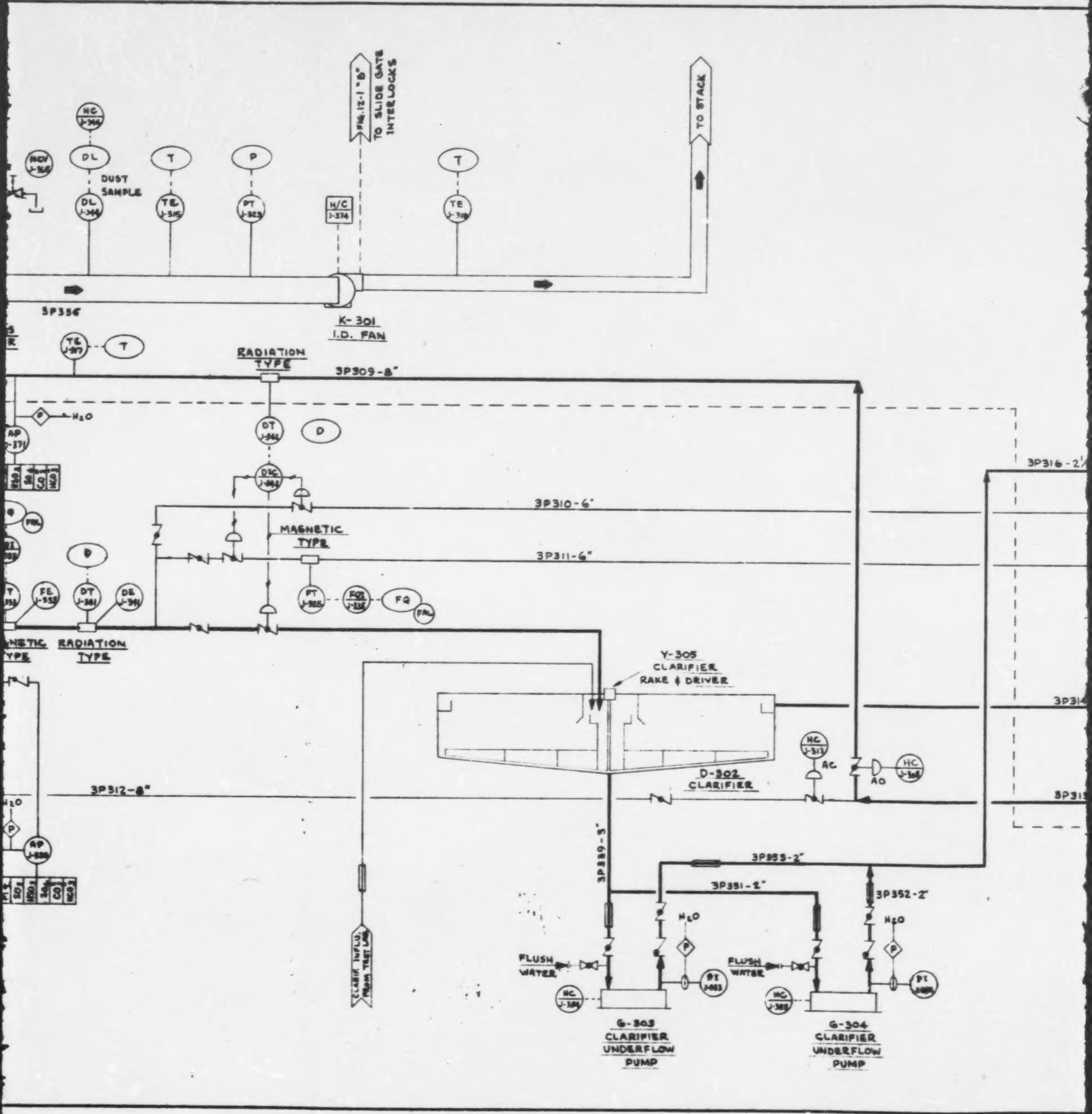
E


VENT
AIR SUPPLY
HCV J-344
PCV J-362
PSV J-364
PCV J-338
HCV J-339
LC J-363
LT J-363
D-304 SURGE TANK
PE J-340
PIT J-340
P
CONDENSATE
Fig. 12.1-1 "A" FLUE GAS
FIG. 12.1-5 "C"
A
AE J-347
SO2
AP J-347
SO3
SAMPLING SYSTEM
AE J-347
A
NOx
AIR SUPPLY
HC J-345
DL
DL J-343
FE J-331
FZ J-331
AP J-347
E-301 REGEN. FLUE GAS COOLER
3P301
FT J-331
FV J-331
TE J-313
T
PS J-380
DPI J-361
FQ
FQI J-331
FIC J-331
TE J-377
T
TE J-379
T
A
PT J-358
HCV J-389
FE J-390
FT J-390
TE J-377
T
FE J-378
FT J-378
FQI J-378
FQ
PI J-376
HC J-381
FROM MASTER LOAD CONTROLLER
FIG. 12.1-1 "D"
TO PRIORITY SELECTOR
FIG. 12.1-1 "E"
TO I.D. FAN TE INTERLOCKS
AIR SUPPLY

A


PLANT WATER
FIG. 3-5 "E"
CO2
O2
H2O
N2
SAMPLING SYSTEM
AE J-348
NOX
AE J-348
SO2
AP J-348
SO3
A
A
TT J-307
T
TE J-307
FIG. 12-1 "C"
PLANT WATER
PI J-305
HCV J-366
HC J-344
DL
DUST SAMPLE
DL J-344
T
TE J-315
T
TE J-314
AP J-348
3P354
P
PT J-380
TE J-379
T
FUTURE
P
PT
PT J-358
P
PT J-357
P
PT J-321
FUTURE
AP
SAMPLING SYSTEM
T
TE J-227
DPI J-328
E-302
FLUE GAS REHEATER
3P356
TE J-317
T
E-301
REGEN. FLUE GAS COOLER
FS
HC J-365
FY J-367
FY J-367
FIC J-367
FT J-367
FE J-367
FQI J-367
FQ
FAL
AND
I/P
3P370-6"
MAG. TYPE
AP J-371
H2O
TE J-379
T
HCV J-357
FE J-310
FT J-310
C-301
FLOODED BED SCRUBBER
FS J-367
HC J-366
FY J-367
FY J-367
FIC J-367
FT J-367
FE J-367
FQI J-367
FQ
FAL
I/P
3P371-2"
MAGNETIC TYPE
3P325-2"
T
TE J-372
FQ
FAL
FQI J-388
FT J-336
FE J-335
D
DT J-361
DE J-341
MAGNETIC TYPE
RADIATION TYPE
TE J-377
T
FQI J-310
FQ
FT J-378
FE J-378
FQI J-378
FQ
AE J-369
AT J-369
A
PH
LAH J-370
3P302-16"
T-301
SCRUBBER EFFLUENT HOLD TANK
Y-303
MIXER
LE J-370
LC J-370
LE J-326
LAL J-326
LC J-326
LS J-326
T
TE J-381
T-305
SCREW CONVEYOR AND INCLINED SCRAPER UNIT
3P307-6"
3P305-6"
3P308-6"
3P306-8"
3P380-6"
3P312-8"
H2O
P
AP J-332
H2O
P
PI J-350
H2O
P
PT J-351
HC J-381
HC J-382
G-301
SCRUBBER EFFLUENT PUMP
G-302
SCRUBBER EFFLUENT PUMP
PI J-362
HC J-383
G-307
REGENERATIVE WATER RECIRCULATING PUMP

B


HC J-366
HCV J-365
DL
DUST SAMPLE
DL J-366
T
TE J-315
P
PT J-323
FIG. 12-1 "B"
TO SLIDE GATE INTERLOCKS
H/C J-374
T
TE J-316
TO STACK
3P356
K-301 I.D. FAN
TE J-317
T
RADIATION TYPE
3P309-8"
H₂O
AP J-371
DT J-344
D
DIC J-344
3P310-6"
MAGNETIC TYPE
3P311-6"
D
FE J-335
DT J-381
DE J-381
FT J-335
FQI J-335
FQ
FAL
MAGNETIC TYPE
RADIATION TYPE
Y-305 CLARIFIER RAKE & DRIVER
3P316-2"
3P314
HC J-313
AC
AO
HC J-318
D-302 CLARIFIER
3P312-8"
3P315
3P339-3"
3P353-2"
3P351-2"
3P352-2"
H₂O
AP J-339
H₂O
H₂O
FLUSH WATER
FLUSH WATER
CLARIF. INFLU. FROM TEST LAB
HC J-384
PI J-383
HC J-385
PI J-385
G-303 CLARIFIER UNDERFLOW PUMP
G-304 CLARIFIER UNDERFLOW PUMP

C

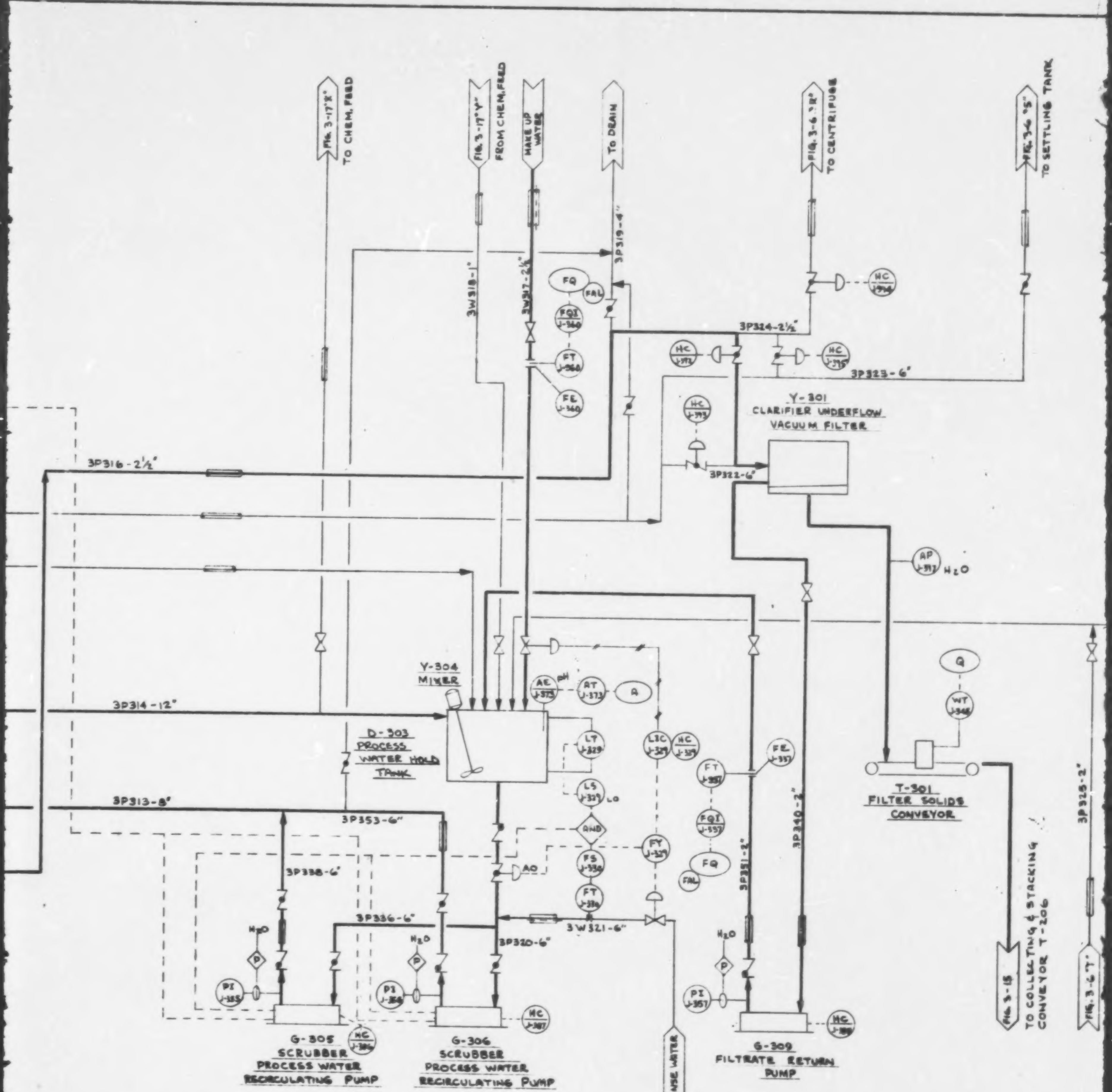


FIG. 3-17 "X"
TO CHEM. FEED
FIG. 3-17 "Y"
FROM CHEM. FEED
MAKE UP WATER
TO DRAIN
FIG. 3-6 "R"
TO CENTRIFUGE
FIG. 3-6 "S"
TO SETTLING TANK
3W318-1"
3W317-2½"
3P319-4"
FQ
FAL
FQI J-360
FT J-360
FE J-360
HC J-394
3P324-2½"
HC J-392
HC J-395
3P323-6"
HC J-393
Y-301
CLARIFIER UNDERFLOW
VACUUM FILTER
3P322-6"
3P316-2½"
AP J-397
H₂O
Y-304
MIXER
AE J-373
pH
AT J-373
A
3P314-12"
D-303
PROCESS
WATER HOLD
TANK
LT J-329
LS J-329
LO
AND
AO
FS J-330
FT J-330
LIC J-329
HC J-329
FY J-329
FT J-357
FE J-357
FQI J-357
FQ
FAL
3P313-8"
3P353-6"
3P338-6"
3P336-6"
3P320-6"
3W321-6"
H₂O
P
PI J-355
PI J-356
HC J-386
HC J-387
G-305
SCRUBBER
PROCESS WATER
RECIRCULATING PUMP
G-306
SCRUBBER
PROCESS WATER
RECIRCULATING PUMP
RINSE WATER
3P351-2"
3P340-2"
H₂O
P
PI J-357
HC J-389
G-309
FILTRATE RETURN
PUMP
Q
WT J-346
T-301
FILTER SOLIDS
CONVEYOR
FIG. 3-15
TO COLLECTING & STACKING
CONVEYOR T-206
3P325-2"
FIG. 3-6 "T"

D

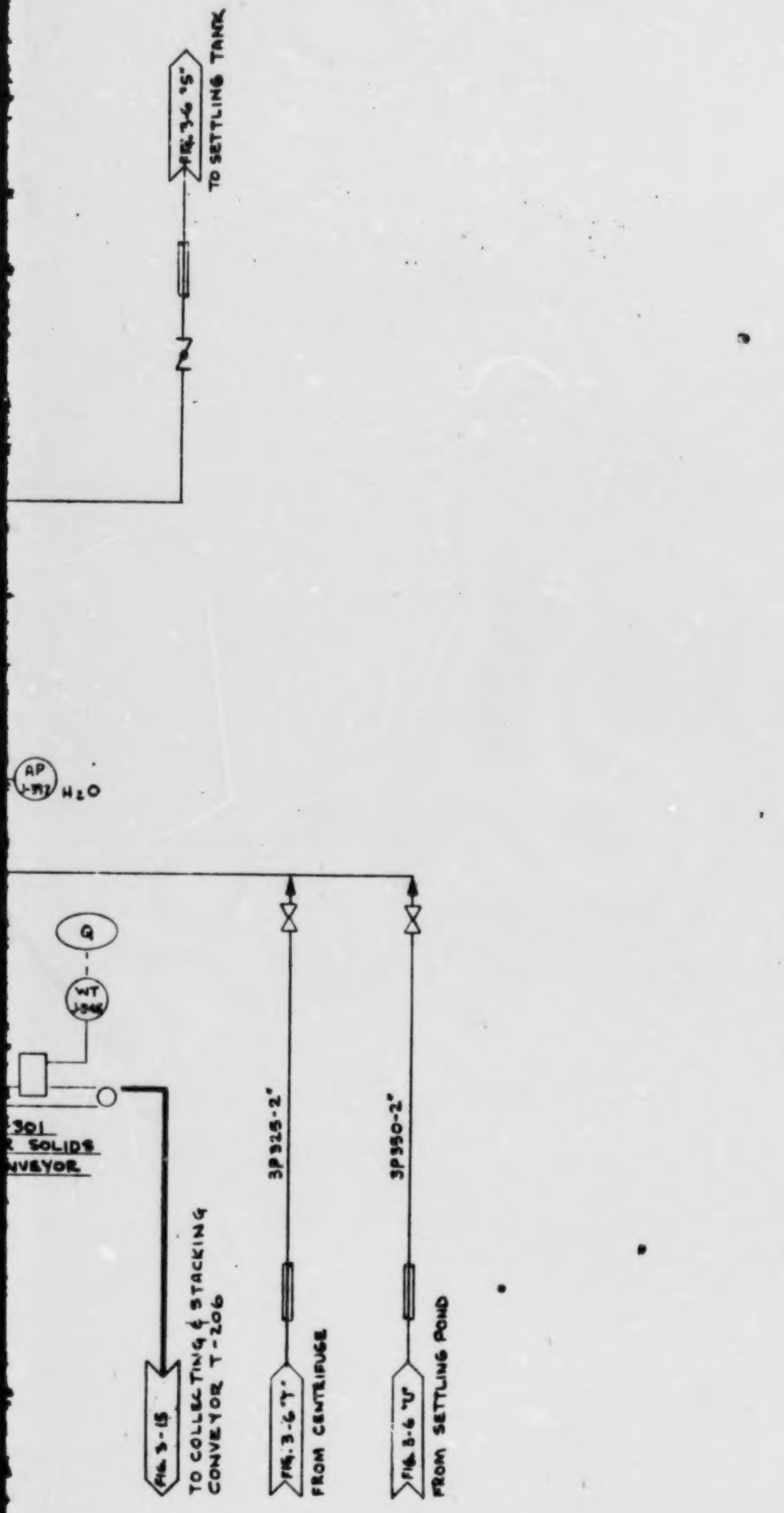


FIG. 3-6 "S"
TO SETTLING TANK
AP
H₂O
Q
WT
301
R SOLIDS
NVEYOR
FIG. 3-15
TO COLLECTING & STACKING CONVEYOR T-206
3P325-2"
FIG. 3-6 "T"
FROM CENTRIFUGE
3P330-2"
FIG. 3-6 "U"
FROM SETTLING POND

NOTE:
FOR GENERAL NOTES, SEE FIGURE 3-5

△								
△								
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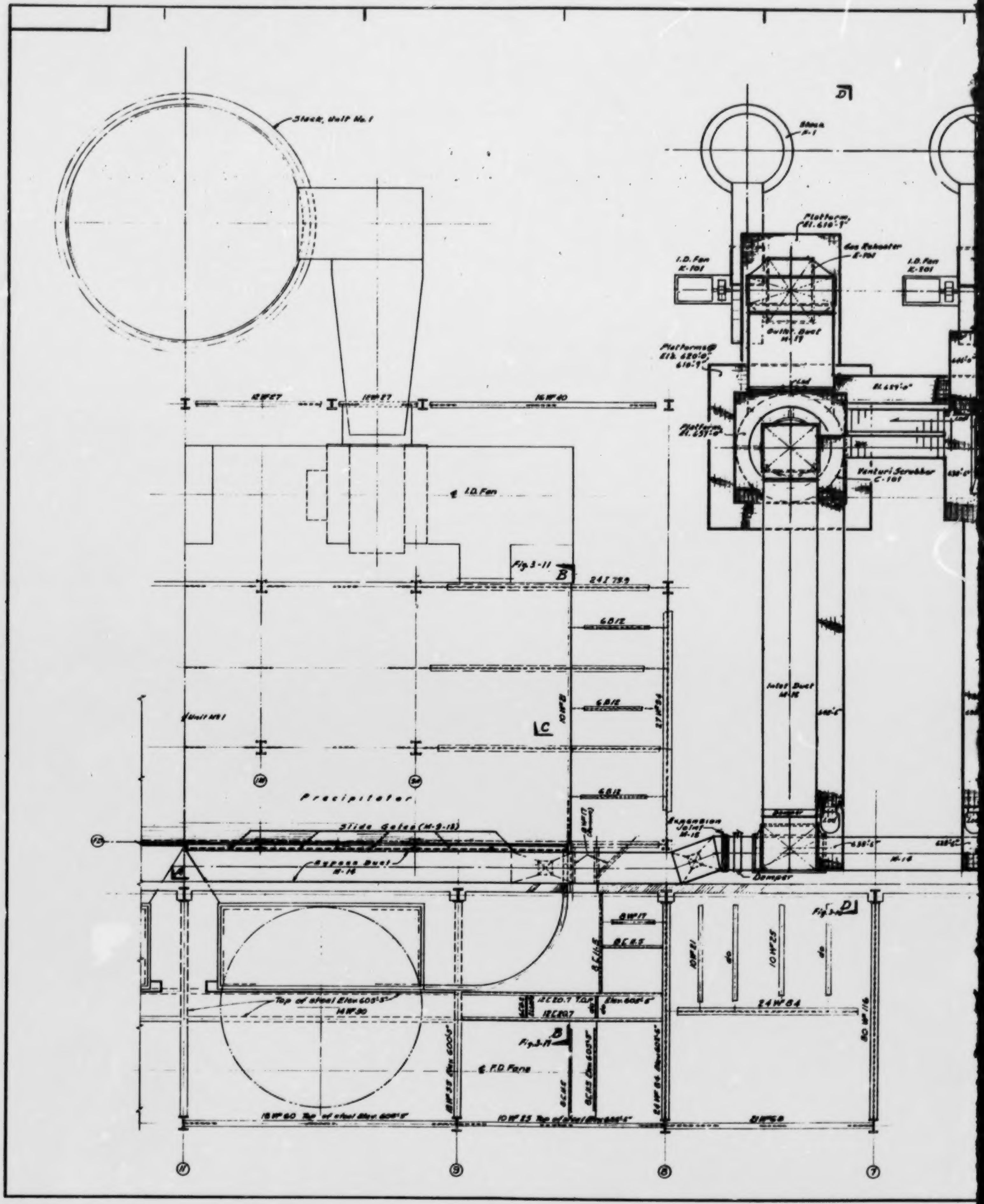
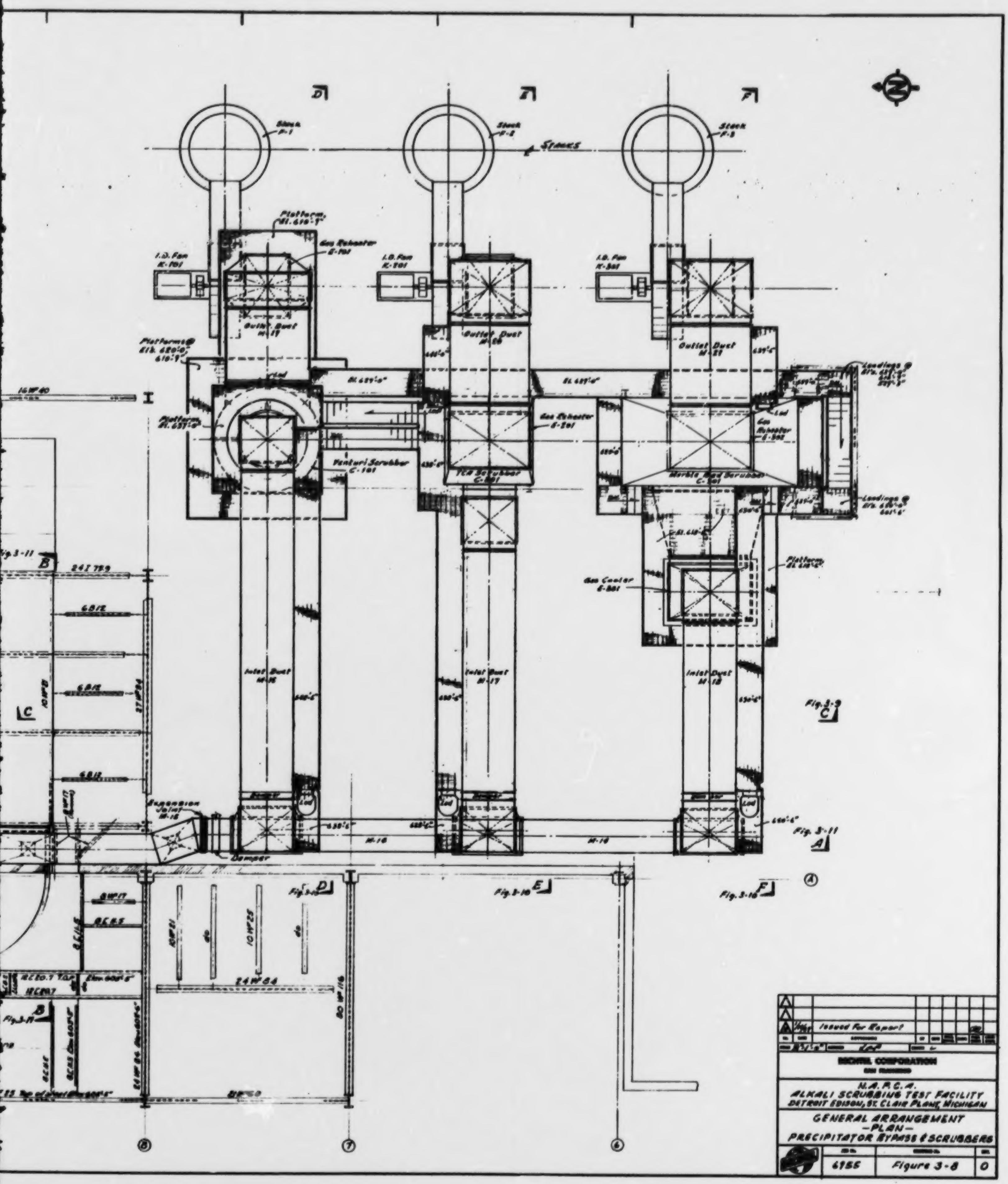
PROCESS PIPING & INSTRUMENTATION DIAGRAM
PLANT NO. 300

JOB NO.	DRAWING NO.	REV.
6955	FIGURE 3-7	0

E


Stack, Unit No. 1
12W27
12W27
16W40
℄ I.D. Fan
Fig. 3-11
B
24I79.9
6B12
6B12
6B12
10W18
27W94
C
Unit No. 1
Precipitator
Slide Gates (M-9-13)
Bypass Duct M-14
D
Stack P-1
Platform El. 610'-1"
Gas Reheater E-101
I.D. Fan K-101
I.D. Fan K-201
Outlet Duct M-17
Platforms @ Elk. 620'-0", 610'-1"
El. 639'-0"
Platform El. 637'-0"
Venturi Scrubber C-101
Inlet Duct M-15
Expansion Joint M-16
Damper
638'-6"
M-16
Fig. 3-10
D
8W17
8C11.5
10W21
do
10W25
do
24W84
Top of steel Elev. 605'-5"
14W30
12C20.7 T.O.S.
12C20.7
Elev. 605'-5"
Fig. 3-11
B
℄ F.D. Fans
8W35 Elev. 600'-5"
8C11.5
8C11.5 Elev. 605'-5"
24W84 Elev. 605'-5"
30W116
18W60 Top of steel Elev. 605'-5"
10W25 Top of steel Elev. 605'-5"
21W68
10
9
8
7

A


Stack F-1
Stack F-2
Stack F-3
℄ Stacks
I.D. Fan K-101
I.D. Fan K-201
I.D. Fan K-301
Gas Reheater E-101
Gas Reheater E-201
Gas Reheater E-301
Outlet Duct M-19
Outlet Duct M-20
Outlet Duct M-21
Venturi Scrubber C-101
TCA Scrubber C-201
Mobile Bed Scrubber C-301
Gas Cooler E-301
Inlet Duct M-16
Inlet Duct M-17
Inlet Duct M-18
Expansion Joint M-15
Damper
M-16
M-14
Platform El. 610'-7"
Platforms @ Els. 620'-0" 610'-7"
Landings @
Platform
Fig. 3-11 B
Fig. 3-11 A
Fig. 3-9 C
Fig. 3-10 D
Fig. 3-10 E
Fig. 3-10 F
D
E
F
C
24 W 76
10 W 25
24 W 84
20 W 116
8
7
6
A

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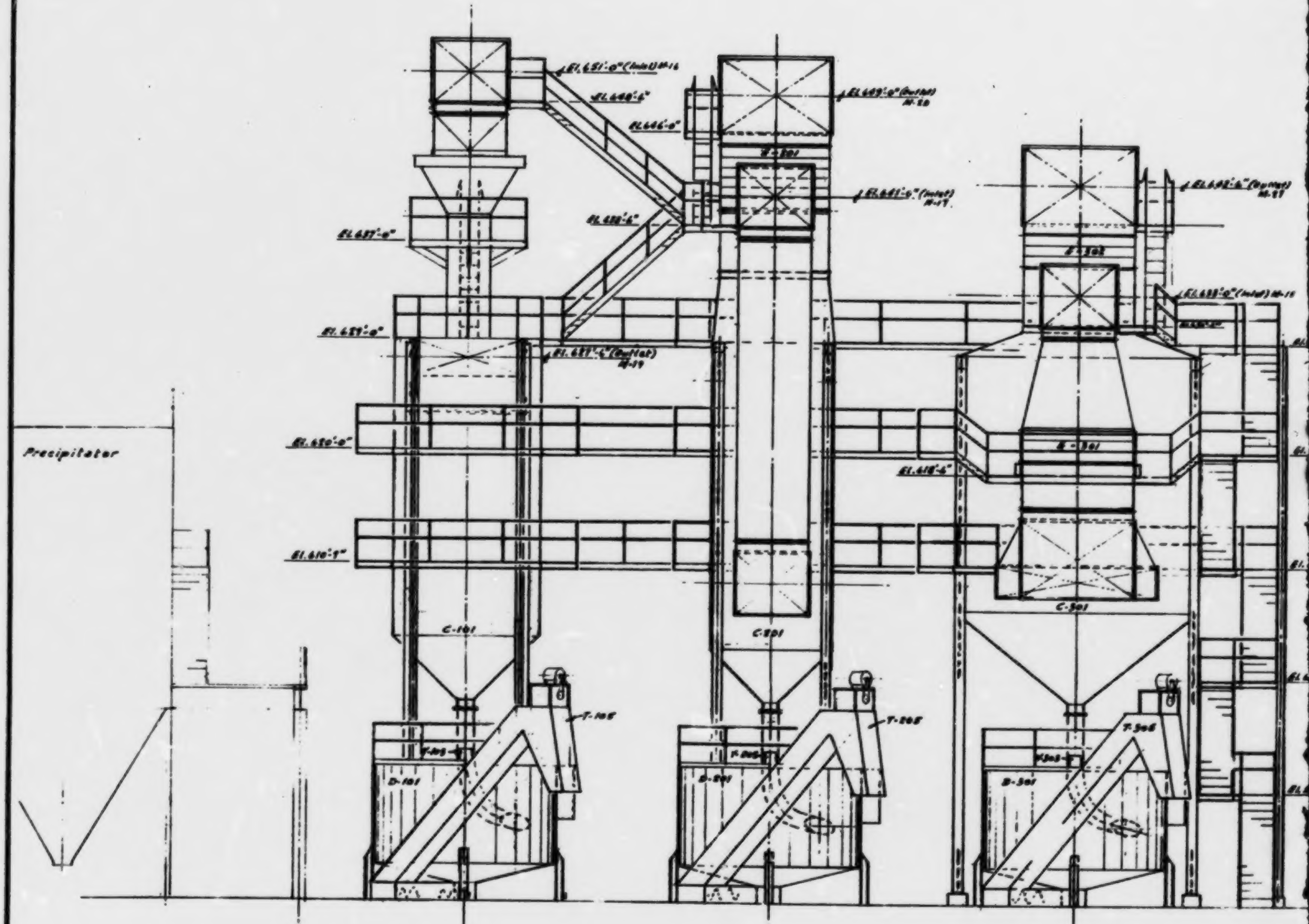
GENERAL ARRANGEMENT
-PLAN-
PRECIPITATOR BYPASS & SCRUBBERS

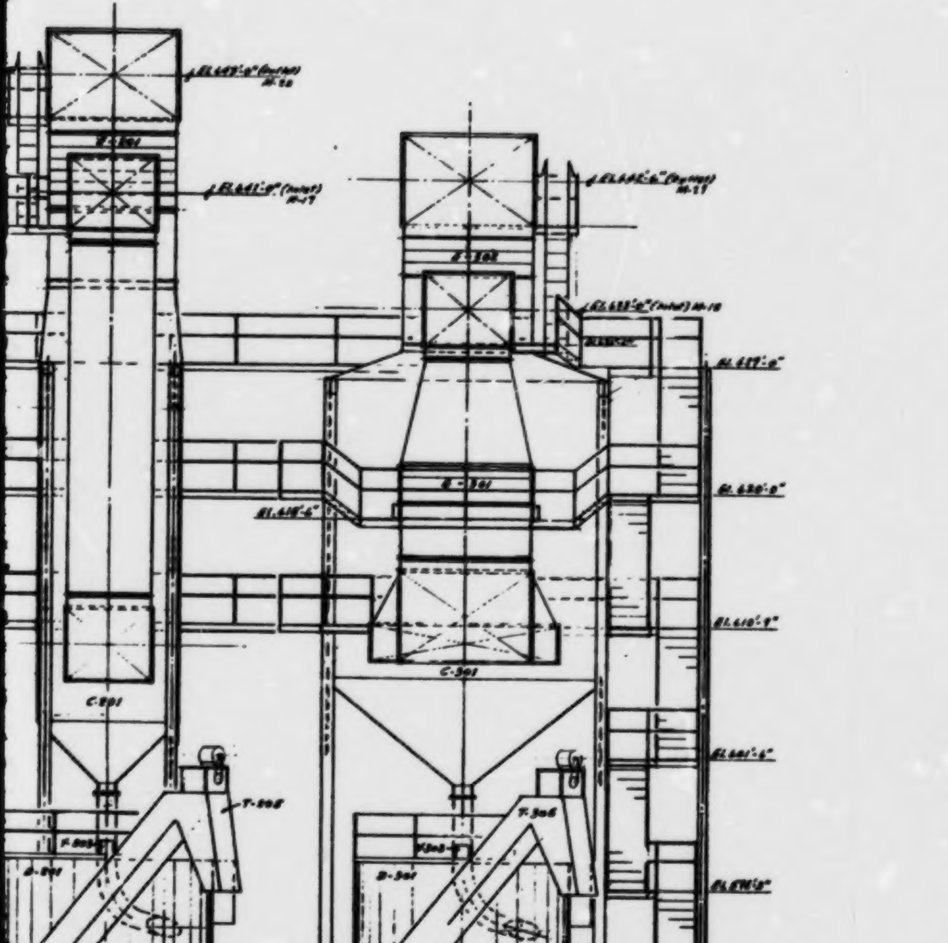
6155 | Figure 3-8 | 0

B


Precipitator
El. 651'-0" (Inlet) M-16
El. 648'-6"
El. 646'-0"
El. 657'-0"
El. 638'-6"
El. 659'-0"
El. 657'-6" (Outlet) M-19
El. 650'-0"
El. 610'-1"
El. 649'-0" (Outlet) M-20
E-201
El. 641'-0" (Inlet) M-17
El. 642'-6" (Outlet) M-21
E-302
El. 633'-0" (Inlet) M-18
E-301
El. 618'-6"
C-101
C-201
C-301
T-105
T-205
T-305
T-103
T-203
T-303
D-101
D-201
D-301
B

ELEVATION C-C
Looking East

A


El. 649'-0" (Outlet)
El. 641'-0" (Inlet)
El. 642'-6" (Outlet)
El. 633'-0" (Inlet)
El. 629'-0"
El. 620'-0"
El. 618'-6"
El. 610'-9"
El. 601'-6"
C-201
C-301
E-301
T-205
T-306
D-201
D-301
Grade, El. 585'-0"

ELEVATION C-C
Looking East

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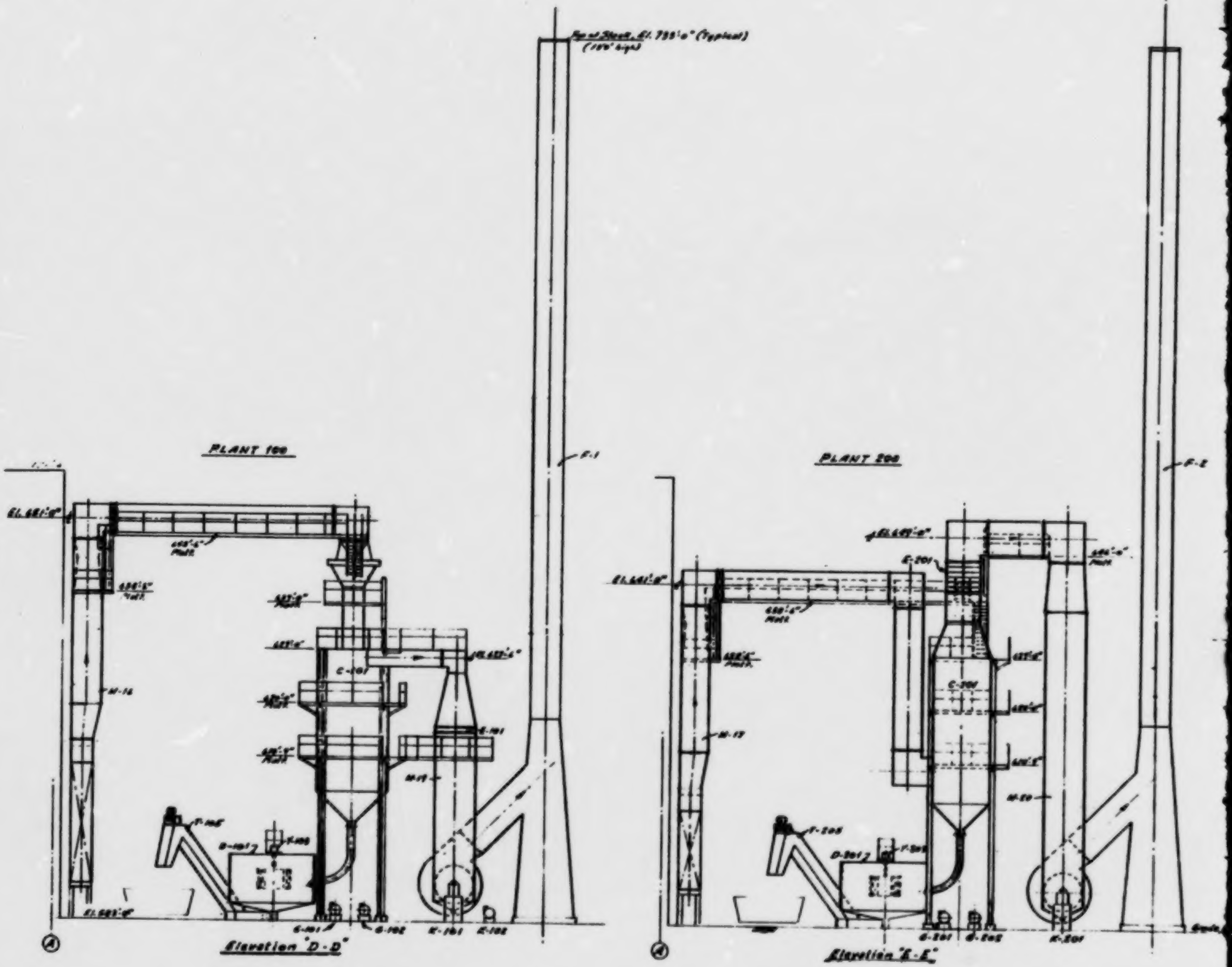
GENERAL ARRANGEMENT
SCRUBBERS
ELEVATION C-C

6955	Figure 3-9	0

B

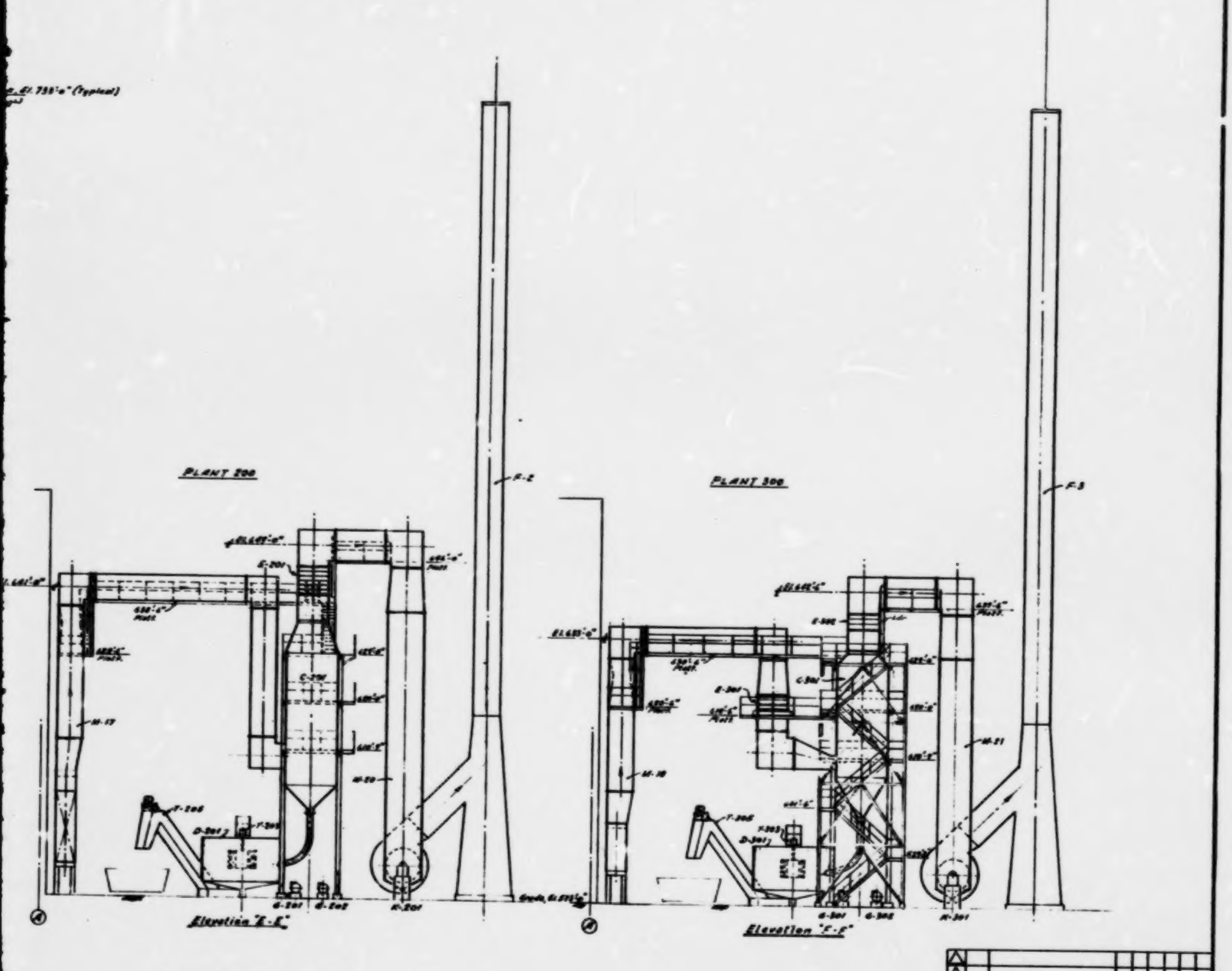

Top of Stack, El. 735'-0" (Typical)
(150' high)
PLANT 100
El. 681'-0"
665'-6" Mezz.
F-1
M-16
C-101
M-19
F-105
D-101
F-106
G-101
G-102
K-101
E-102
E-101
El. 665'-0"
PLANT 200
El. 681'-0"
El. 691'-0"
E-201
C-201
M-17
M-20
F-205
D-201
F-206
G-201
G-202
K-201
F-2
A

Elevation "D-D"

Elevation "E-E"

All Elevations "Looking North"

A


El. 735'-0" (Typical)
PLANT 200
PLANT 300
F-2
F-3
E-201
E-301
C-201
C-301
M-17
M-18
M-20
M-21
T-206
T-306
D-201
D-301
G-201
G-202
G-301
G-302
K-201
K-301
Elevation "E-E"
Elevation "F-F"

All Elevations "Looking North"

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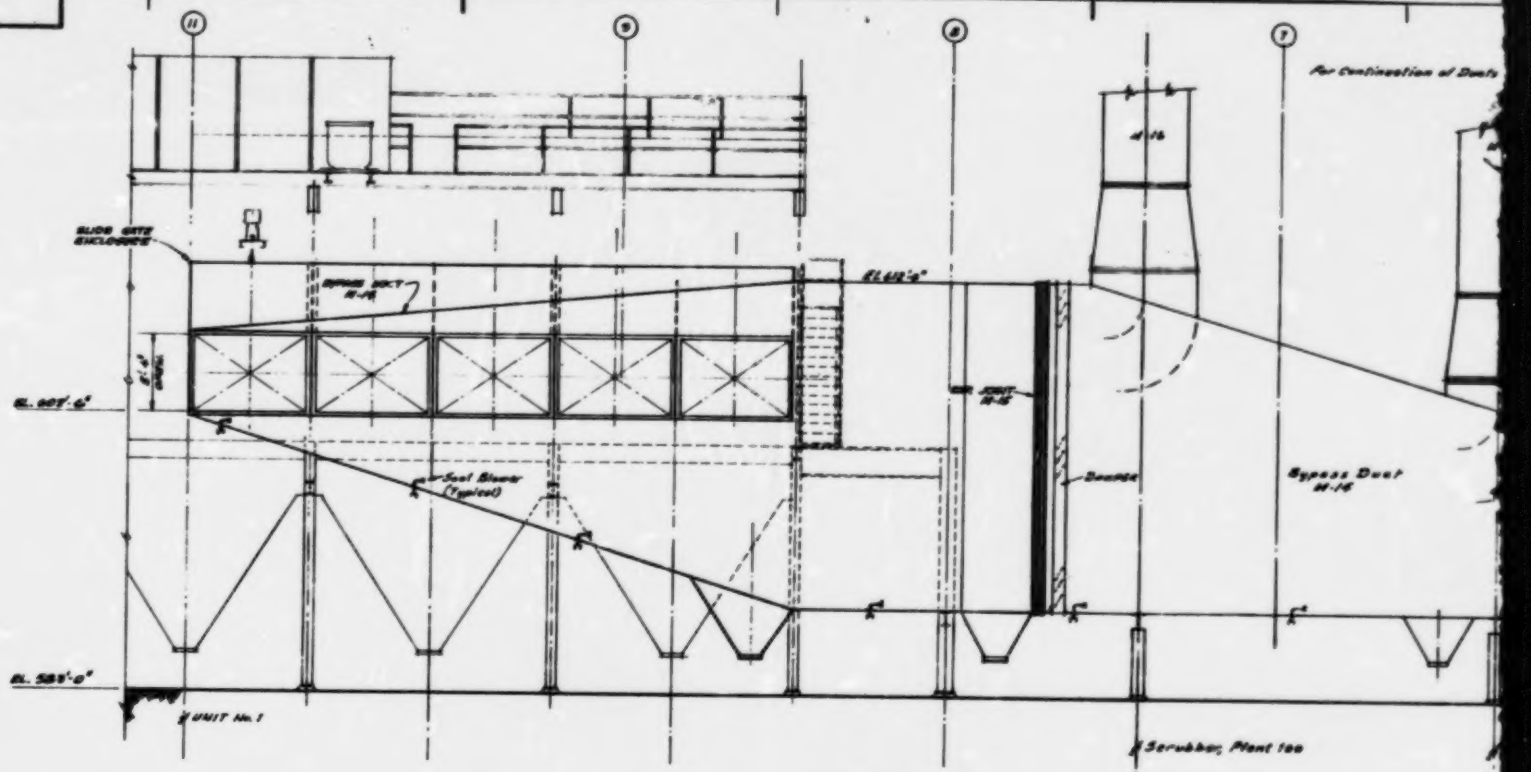
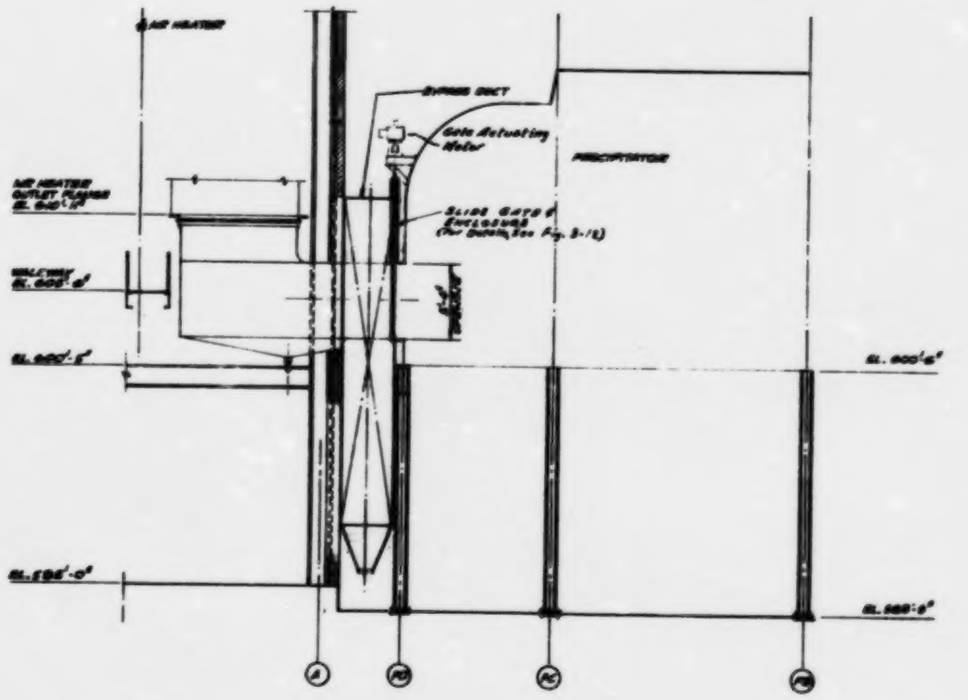
GENERAL ARRANGEMENT
SCRUBBERS
ELEVATIONS D-D, E-E & F-F

6955	Figure 3-10	0

B

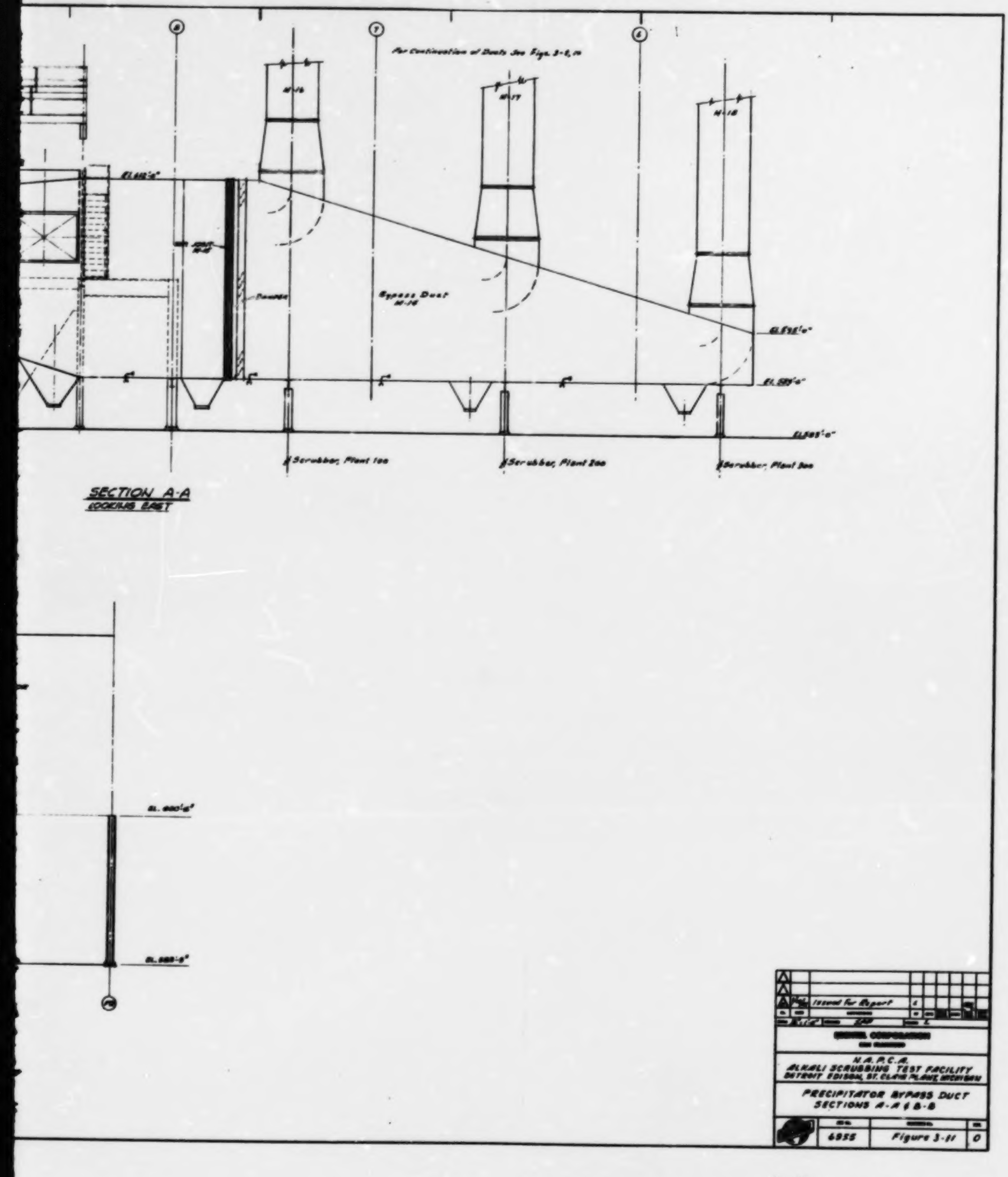

Slide Gate Enclosure
Bypass Duct H-16
EL. 612'-0"
EL. 607'-6"
Soot Blower (Typical)
EL. 585'-0"
℄ Unit No. 1
Exp. Joint H-15
Damper
H-16
Bypass Duct H-16
℄ Scrubber, Plant 100
For Continuation of Ducts
11
9
8
7

SECTION A-A
LOOKING EAST


℄ Air Heater
Air Heater Outlet Flange
Walkway EL. 605'-0"
EL. 600'-5"
EL. 595'-0"
Bypass Duct
Gate Actuating Motor
Precipitator
Slide Gate & Enclosure (For Details See Fig. 3-12)
EL. 600'-6"
A
PD
PC
PB

SECTION B-B
LOOKING NORTH

A


For Continuation of Ducts See Figs. 3-8, 10
8
7
6
M-16
M-17
M-18
El. 612'-0"
Damper
Bypass Duct
M-16
El. 592'-0"
El. 589'-0"
El. 585'-0"
℄ Scrubber, Plant 100
℄ Scrubber, Plant 200
℄ Scrubber, Plant 300
El. 600'-0"
El. 585'-0"
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6955

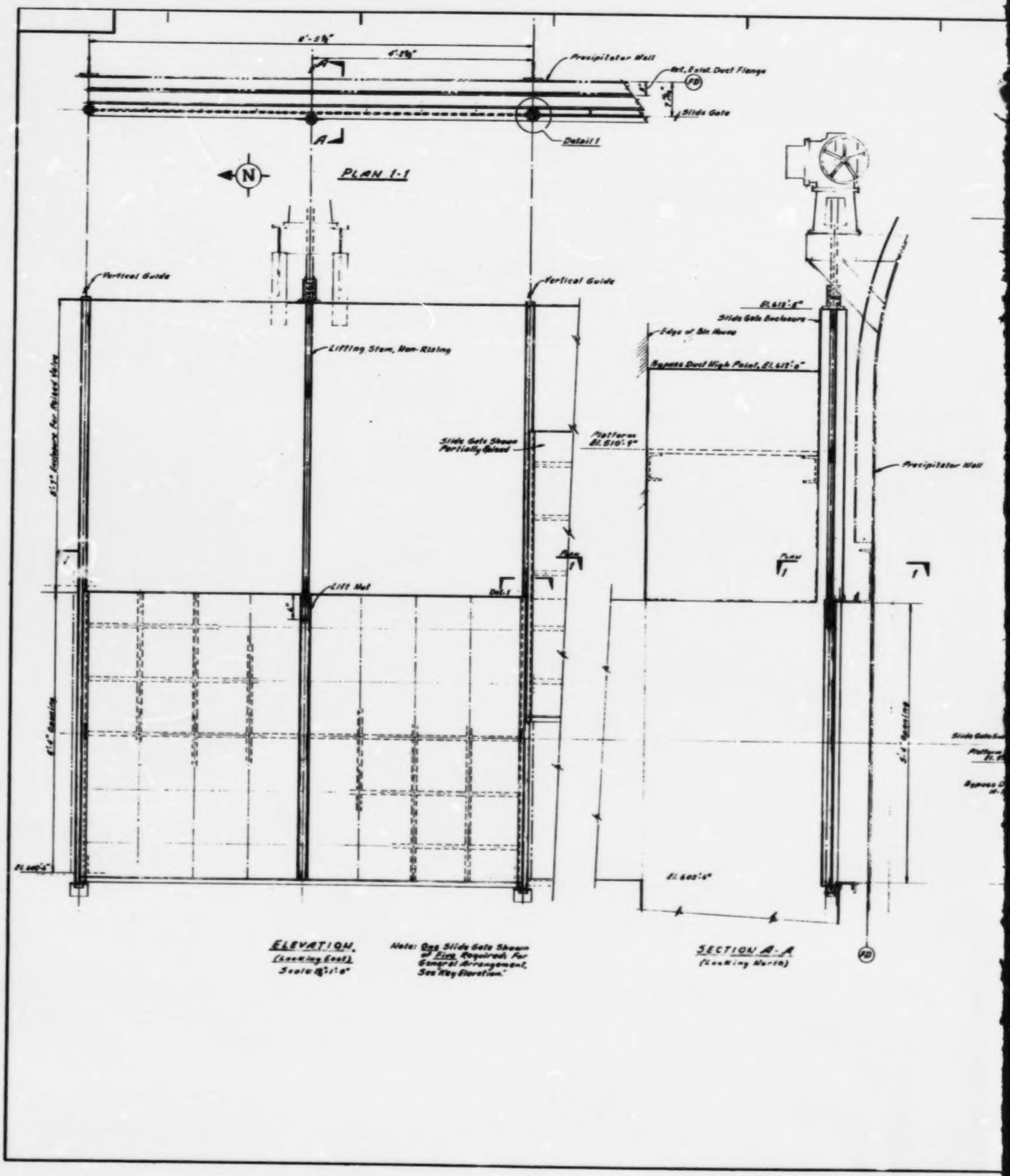
SECTION A-A
LOOKING EAST

N.A.P.C.A.
ALKALI SCRUBBING TEST FACILITY
DETROIT EDISON, ST. CLAIR PLANT, MICHIGAN

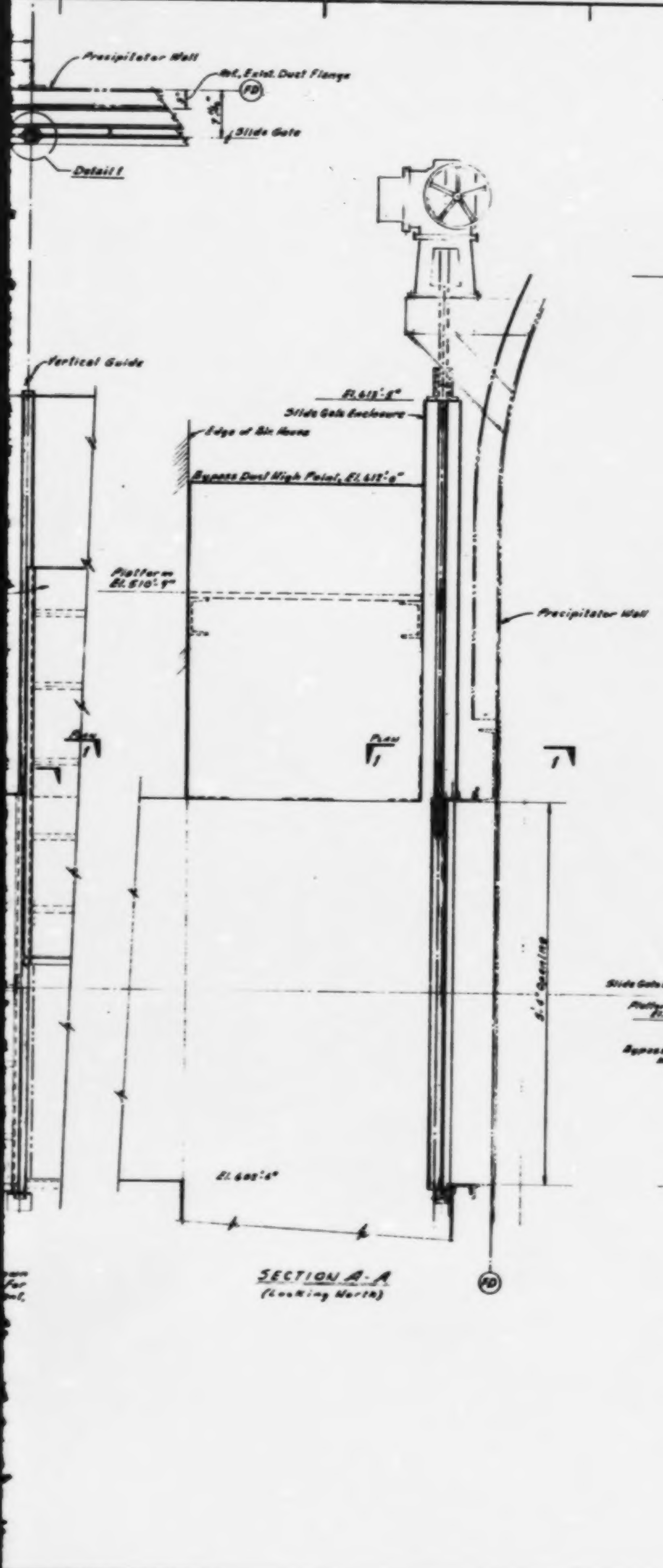
PRECIPITATOR BYPASS DUCT
SECTIONS A-A & B-B

Figure 3-11

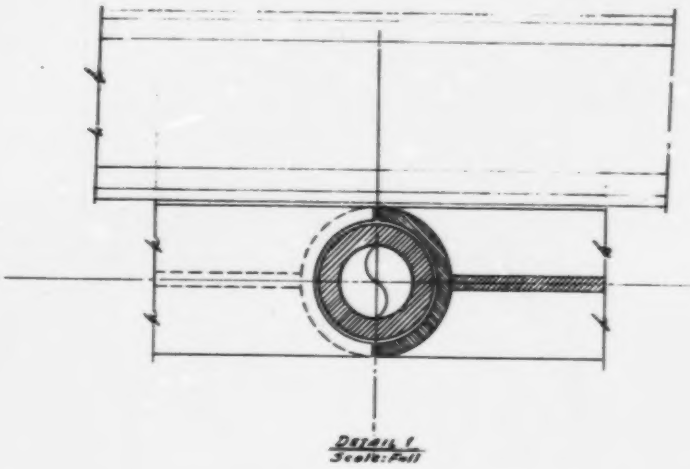
B


8'-5½"
4'-2½"
Precipitator Wall
Ref. Exist. Duct Flange
FD
Slide Gate
A
Detail 1
N
PLAN 1-1
Vertical Guide
Vertical Guide
Lifting Stem, Non-Rising
Slide Gate Shown Partially Raised
Platform El. 610'-9"
Lift Nut
Det. 1
Plan 1
El. 603'-6"
6'-4" Opening
El. 613'-5"
Slide Gate Enclosure
Edge of Bin House
Bypass Duct High Point, El. 613'-0"
Precipitator Wall
Plan 1
1
El. 603'-6"
5'-4" Opening
FD
ELEVATION
(Looking East)
Scale ⅜"=1'-0"
Note: One Slide Gate Shown of Five Required. For General Arrangement, See "Key Elevation."
SECTION A-A
(Looking North)

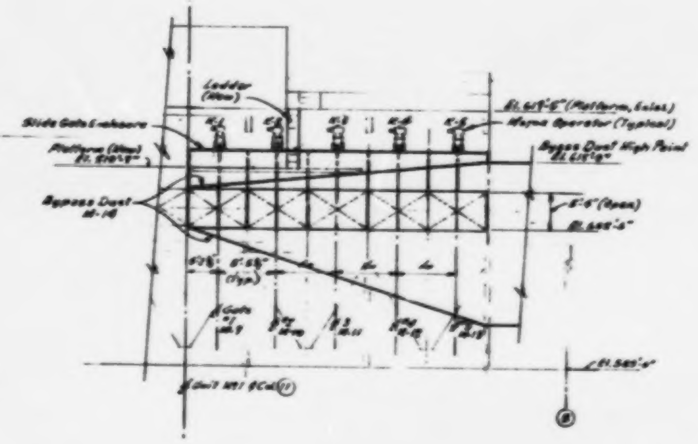
A


Precipitator Wall
Ref. Exist. Duct Flange
Slide Gate
Detail 1
Vertical Guide
El. 613'-5"
Slide Gate Enclosure
Edge of Bin House
Bypass Duct High Point, El. 613'-0"
Platform El. 510'-9"
Precipitator Wall
Plan 1
5'-6" Opening
El. 603'-6"
FD

SECTION A-A
(Looking North)



DETAIL 1
Scale: Full


Ladder (New)
El. 619'-5" (Platform, Exist.)
Slide Gate Enclosure
Motor Operator (Typical)
Platform (New) El. 610'-9"
Bypass Duct High Point El. 615'-0"
Bypass Duct
5'-6" (Open)
(Typ)
Unit No. 1 Col.
El. 585'-0"

KEY ELEVATION
(Looking East)
Scale: ⅛"=1'-0"

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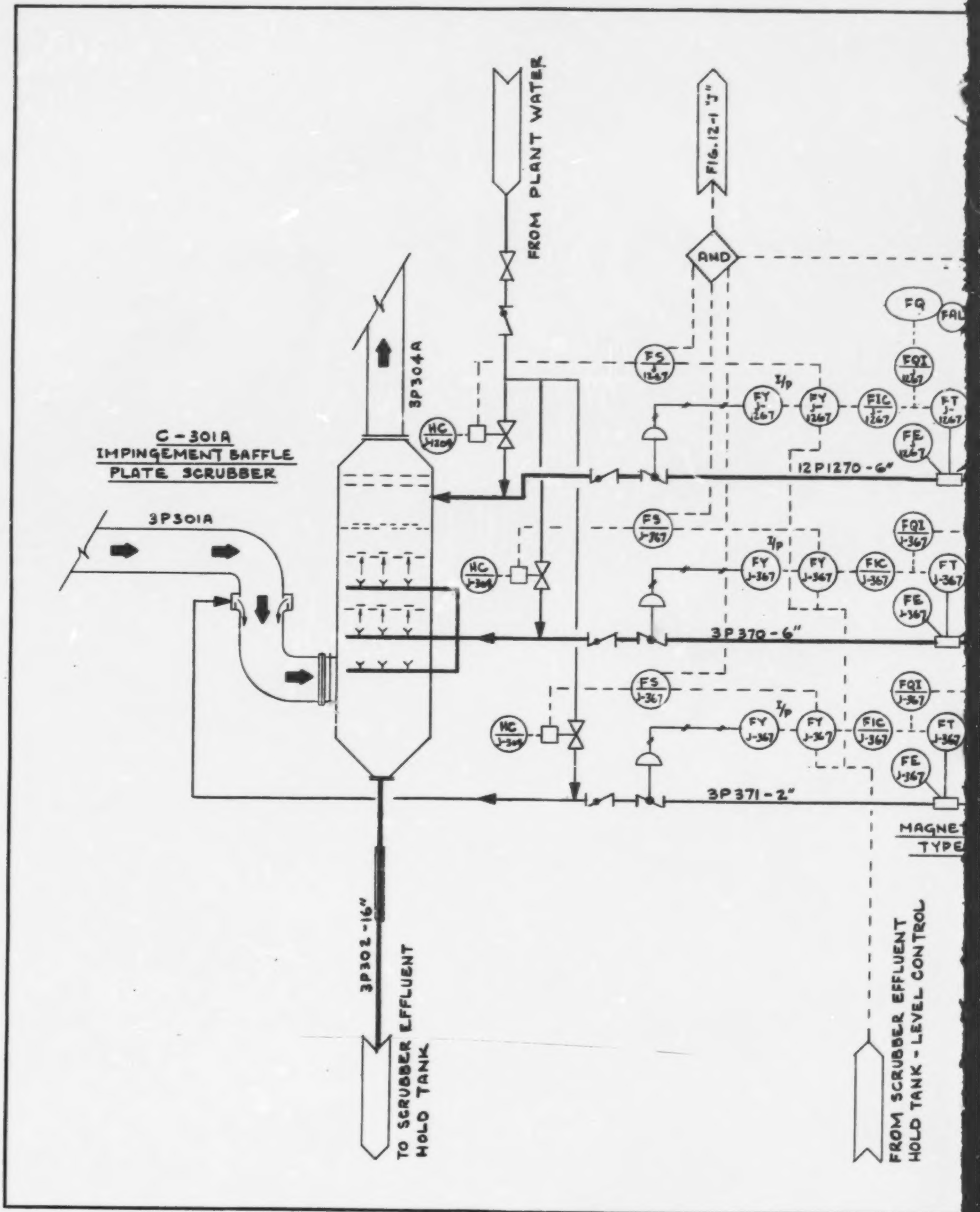
ALKALI SCRUBBING TEST FACILITY
DETROIT EDISON, ST. CLAIR PLANT, MICHIGAN

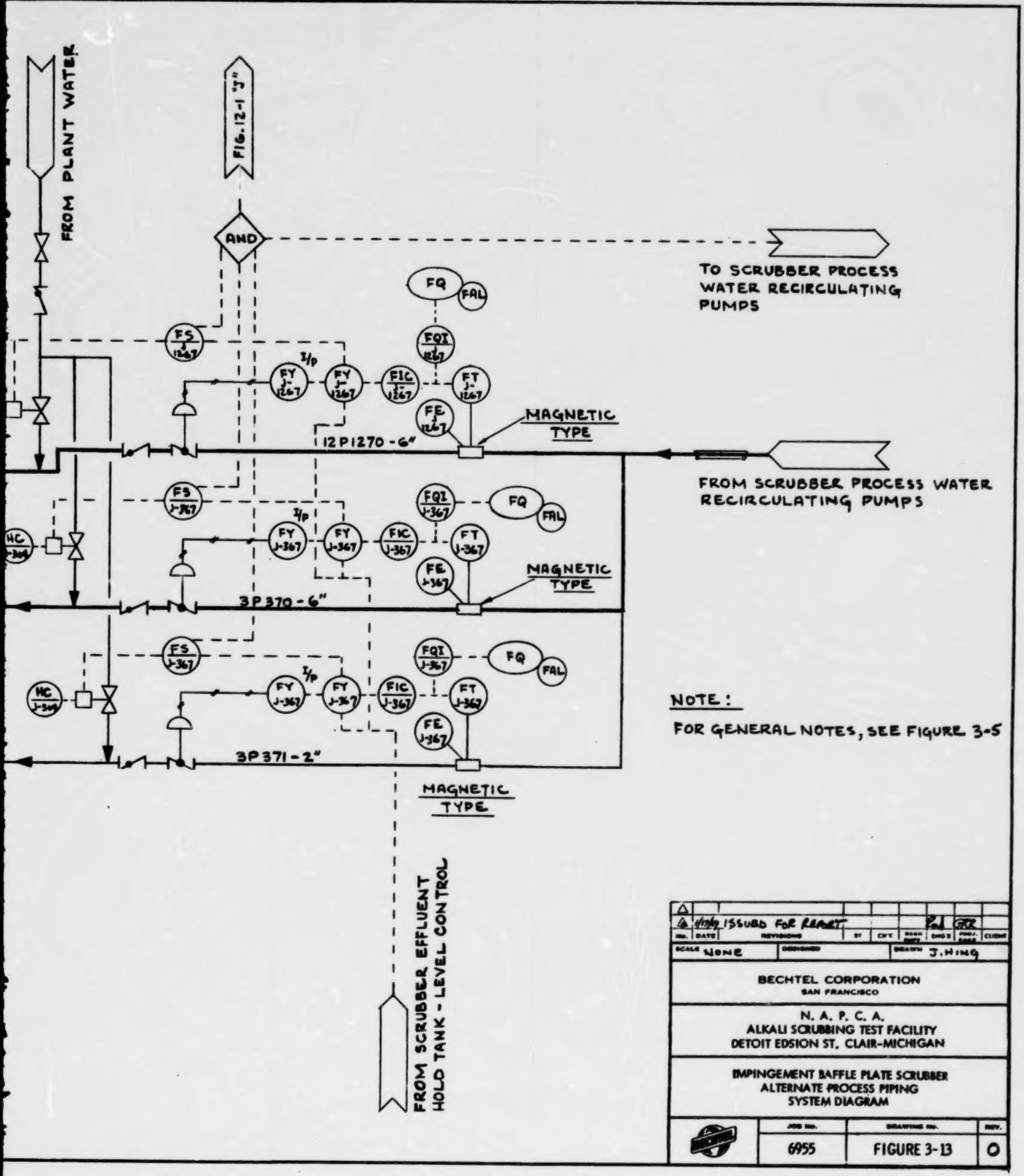
— DETAILS —
PRECIPITATOR BYPASS SLIDE GATE

6955	Figure 3-12	0

B


FROM PLANT WATER
FIG. 12-1 "J"
AND
FQ
FAL
3P304A
C-301A
IMPINGEMENT BAFFLE
PLATE SCRUBBER
HC J-1209
FS J 1267
FY J-1267
I/P
FY J-1267
FIC J-1267
FQI J-1267
FT J-1267
FE J 1267
12P1270-6"
3P301A
FS J-367
HC J-309
FY J-367
I/P
FY J-367
FIC J-367
FQI J-367
FT J-367
FE J-367
3P370-6"
FS J-367
HC J-309
FY J-367
I/P
FY J-367
FIC J-367
FQI J-367
FT J-367
FE J-367
3P371-2"
MAGNET
TYPE
3P302-16"
TO SCRUBBER EFFLUENT
HOLD TANK
FROM SCRUBBER EFFLUENT
HOLD TANK - LEVEL CONTROL

A


FROM PLANT WATER
FIG. 12-1 "J"
AND
TO SCRUBBER PROCESS WATER RECIRCULATING PUMPS
FQ
FAL
FQI J-1267
FS J-1267
I/P
FY J-1267
FY J-1267
FIC J-1267
FT J-1267
FE J-1267
MAGNETIC TYPE
12P1270-6"
FROM SCRUBBER PROCESS WATER RECIRCULATING PUMPS
FS J-367
FQI J-367
FQ
FAL
HC J-369
FY J-367
FY J-367
FIC J-367
FT J-367
FE J-367
MAGNETIC TYPE
3P370-6"
FS J-367
FQI J-367
FQ
FAL
HC J-369
FY J-367
FY J-367
FIC J-367
FT J-367
FE J-367
3P371-2"
MAGNETIC TYPE
FROM SCRUBBER EFFLUENT HOLD TANK - LEVEL CONTROL

NOTE:

FOR GENERAL NOTES, SEE FIGURE 3-5

NO.	DATE	REVISIONS	BY	CH'K		ENG'G		CLIENT
0	1/17/69	ISSUED FOR REPORT					GRR	

SCALE NONE | DESIGNED | DRAWN J. HING

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SAN FRANCISCO

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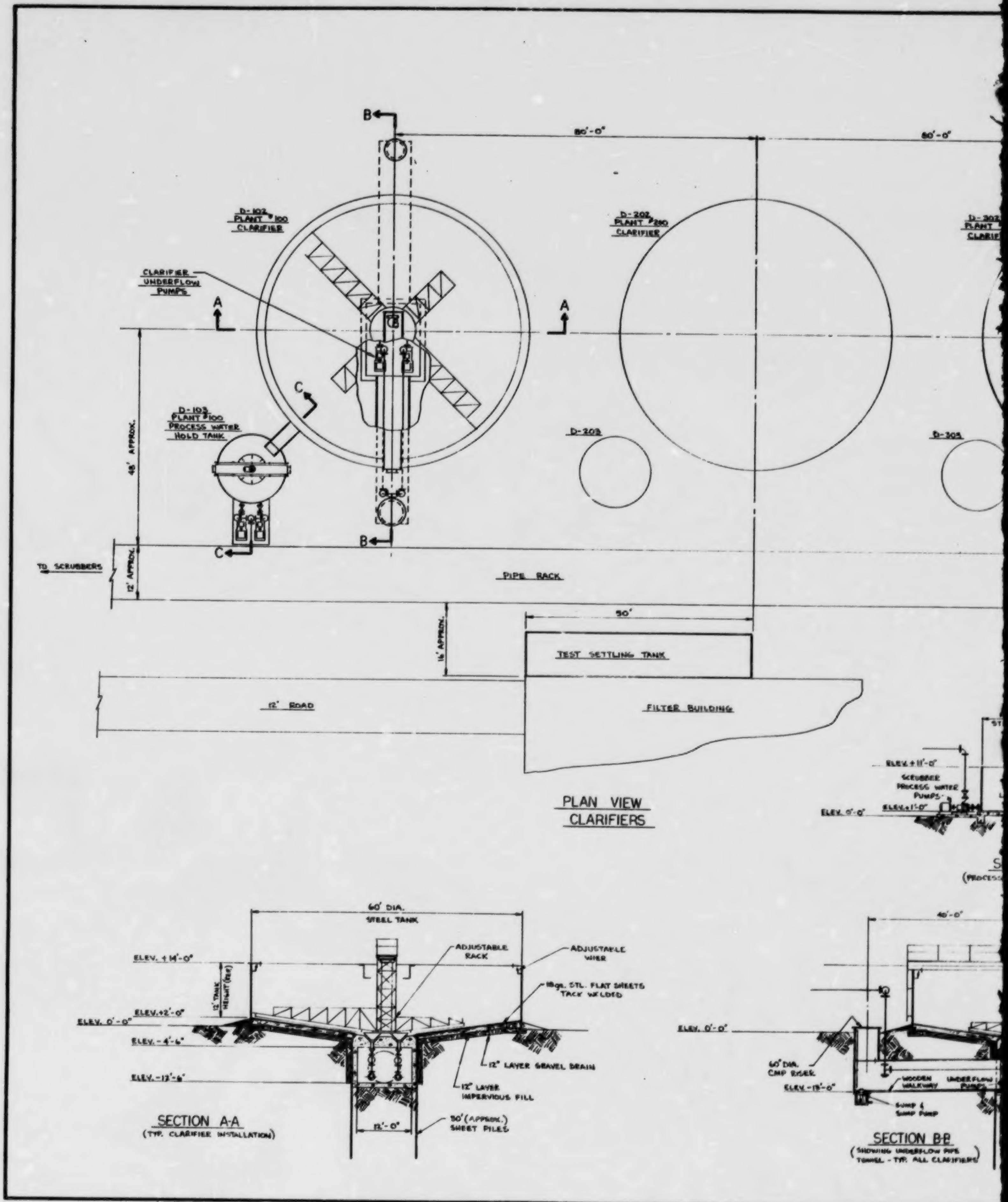
DETOIT EDSION ST. CLAIR-MICHIGAN

IMPINGEMENT BAFFLE PLATE SCRUBBER
ALTERNATE PROCESS PIPING
SYSTEM DIAGRAM

JOB No.	DRAWING No.	REV.
6955	FIGURE 3-13	0

B

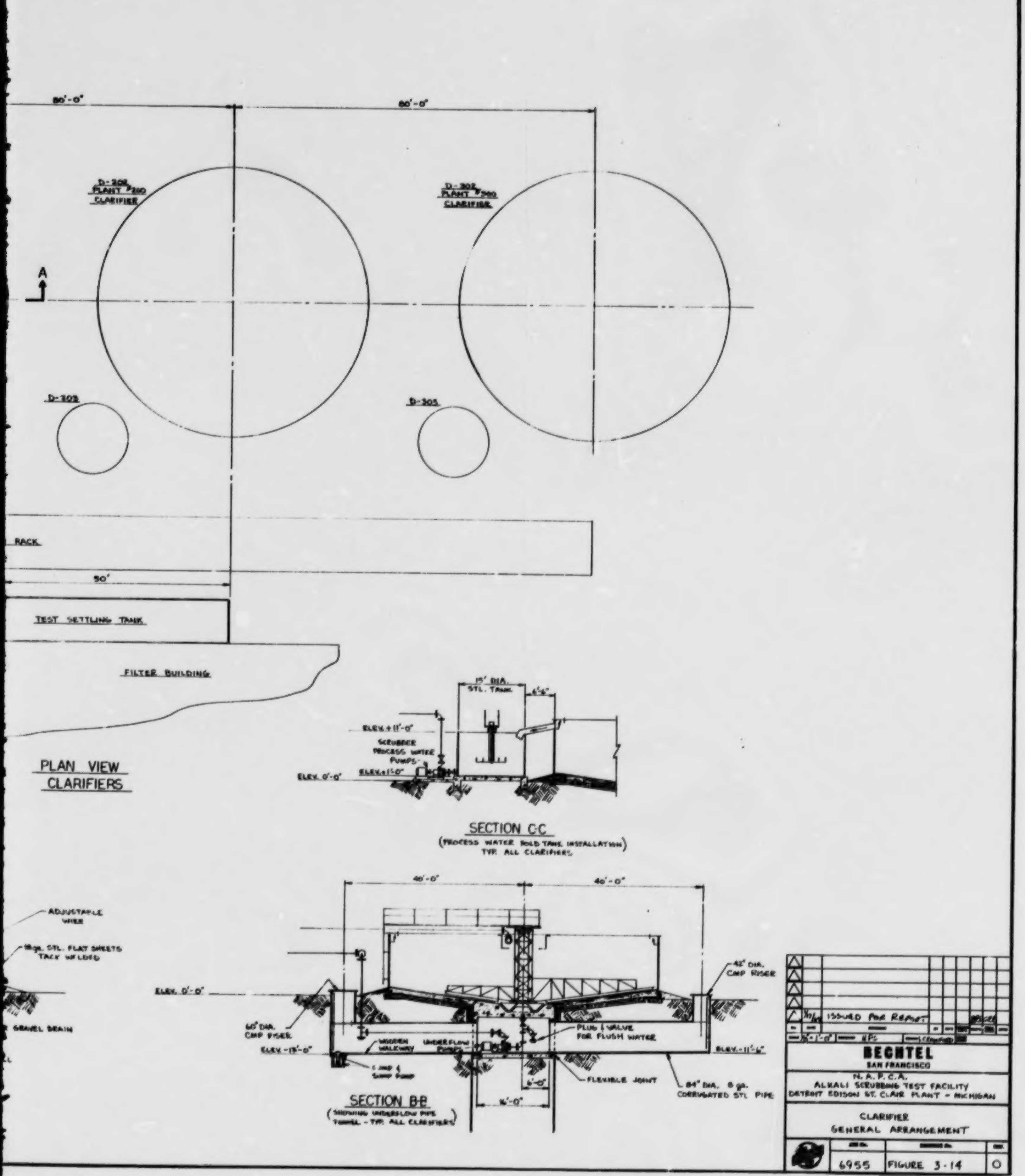

PLAN VIEW
CLARIFIERS

SECTION A-A
(TYP. CLARIFIER INSTALLATION)

SECTION B-B
(SHOWING UNDERFLOW PIPE TUNNEL - TYP. ALL CLARIFIERS)

B
B
80'-0"
80'-0"
D-102
PLANT #100
CLARIFIER
D-202
PLANT #200
CLARIFIER
D-302
PLANT
CLARIF
CLARIFIER
UNDERFLOW
PUMPS
A
A
C
C
D-103
PLANT #100
PROCESS WATER
HOLD TANK
D-203
D-303
48' APPROX.
12' APPROX.
TO SCRUBBERS
PIPE RACK
50'
16' APPROX.
TEST SETTLING TANK
12' ROAD
FILTER BUILDING
ST
ELEV. +11'-0"
SCRUBBER
PROCESS WATER
PUMPS
ELEV. +1'-0"
ELEV. 0'-0"
S
(PROCESS
60' DIA.
STEEL TANK
ADJUSTABLE
RACK
ADJUSTABLE
WIER
ELEV. +14'-0"
12' TANK HEIGHT (REF.)
18ga. STL. FLAT SHEETS
TACK WELDED
ELEV. +2'-0"
ELEV. 0'-0"
ELEV. -4'-6"
ELEV. -12'-6"
12" LAYER GRAVEL DRAIN
12" LAYER
IMPERVIOUS FILL
12'-0"
30' (APPROX.)
SHEET PILES
40'-0"
ELEV. 0'-0"
60' DIA.
CMP RISER
ELEV. -13'-0"
WOODEN
WALKWAY
UNDERFLOW
PUMPS
SUMP &
SUMP PUMP

A


80'-0"
80'-0"
D-202
PLANT #200
CLARIFIER
D-302
PLANT #300
CLARIFIER
A
D-203
D-305
RACK
50'
TEST SETTLING TANK
FILTER BUILDING
PLAN VIEW
CLARIFIERS
15' DIA.
STL. TANK
6'-6"
ELEV. + 11'-0"
SCRUBBER
PROCESS WATER
PUMPS
ELEV. + 1'-0"
ELEV. 0'-0"
SECTION C-C
(PROCESS WATER HOLD TANK INSTALLATION)
TYP. ALL CLARIFIERS
40'-0"
40'-0"
ADJUSTABLE
WIER
18ga. STL. FLAT SHEETS
TACK WELDED
GRAVEL DRAIN
ELEV. 0'-0"
42" DIA.
CMP RISER
60" DIA.
CMP RISER
WOODEN
WALKWAY
UNDERFLOW
PUMPS
PLUG & VALVE
FOR FLUSH WATER
ELEV. -13'-0"
ELEV. -11'-6"
SUMP &
SUMP PUMP
FLEXIBLE JOINT
84" DIA. 8 ga.
CORRUGATED STL. PIPE
6'-0"
16'-0"
SECTION B-B
(SHOWING UNDERFLOW PIPE
TUNNEL - TYP. ALL CLARIFIERS)
ISSUED FOR REPORT
3/8" = 1'-0"
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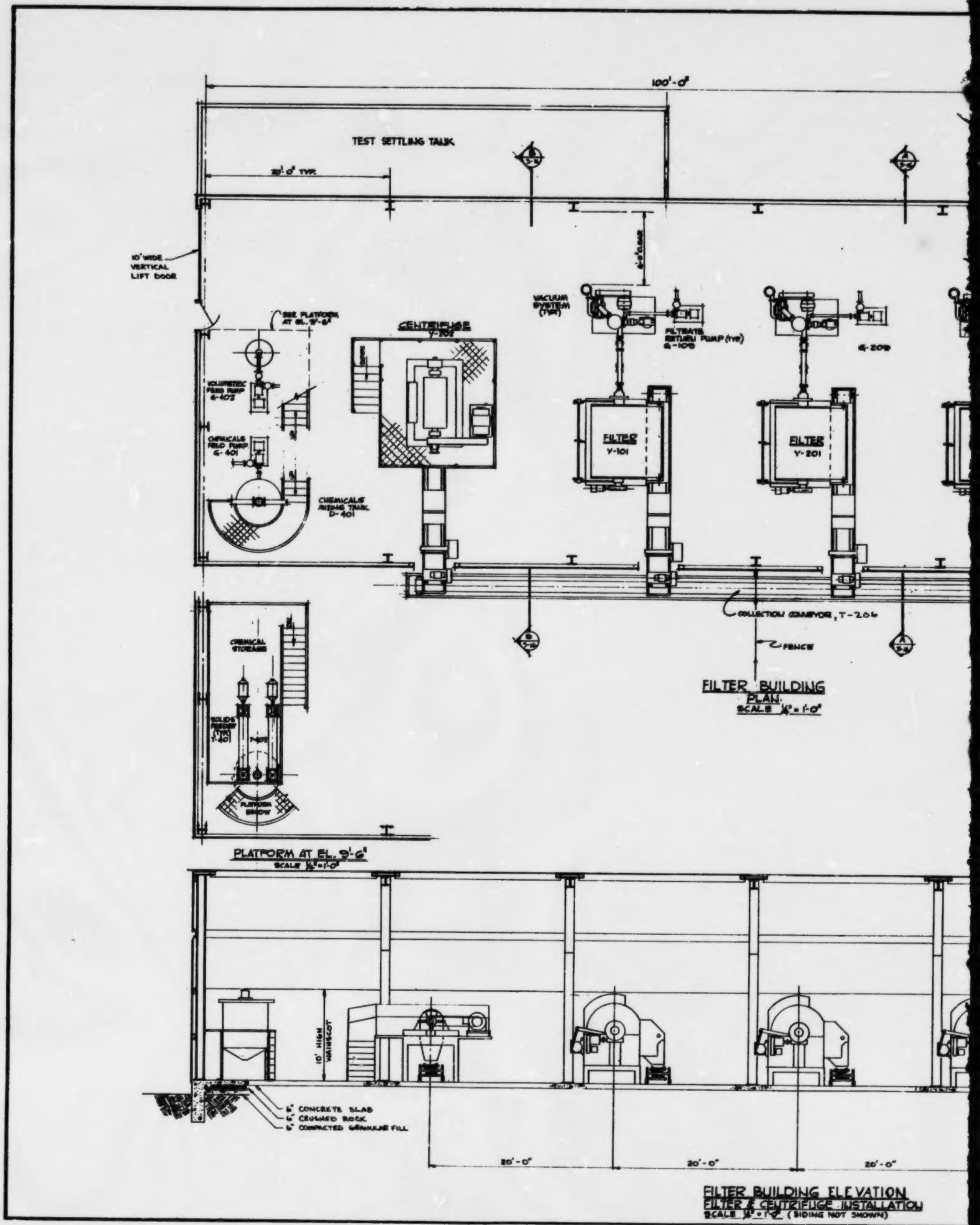
DETROIT EDISON ST. CLAIR PLANT - MICHIGAN
CLARIFIER
GENERAL ARRANGEMENT
6955
FIGURE 3-14
0

B

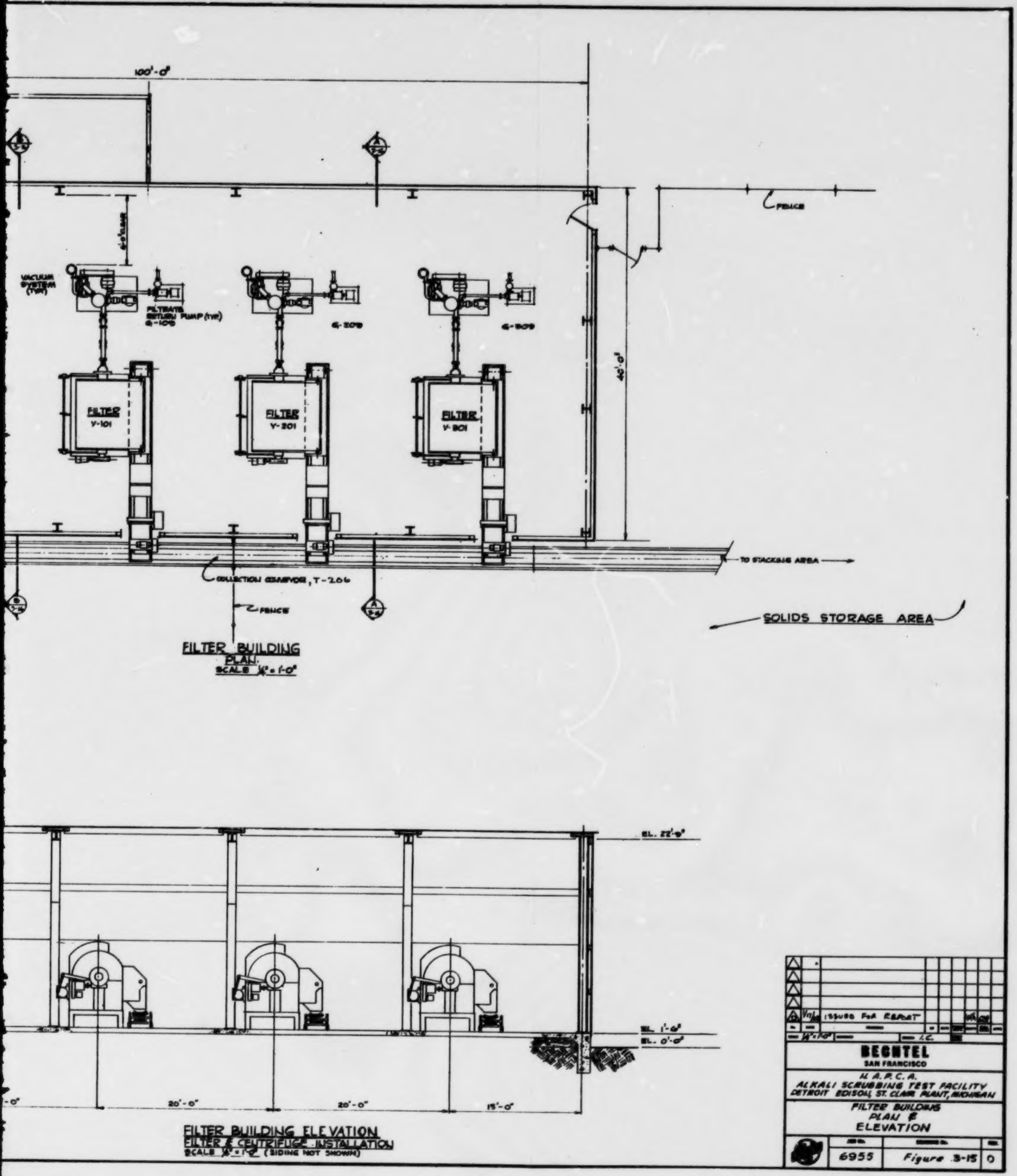

100'-0"
TEST SETTLING TANK
20'-0" TYP.
10' WIDE VERTICAL LIFT DOOR
6'-0" CLEAR
VACUUM SYSTEM (TYP)
FILTRATE RETURN PUMP (TYP) G-109
G-209
SEE PLATFORM AT EL. 9'-6"
CENTRIFUGE Y-302
VOLUMETRIC FEED PUMP G-402
CHEMICALS FEED PUMP G-401
CHEMICALS MIXING TANK D-401
FILTER Y-101
FILTER Y-201
COLLECTION CONVEYOR, T-206
FENCE
CHEMICAL STORAGE
SOLIDS FEEDER (TYP) T-401
T-402
PLATFORM BELOW
10' HIGH WAINSCOT
6" CONCRETE SLAB
6" CRUSHED ROCK
6" COMPACTED GRANULAR FILL
20'-0"
20'-0"
20'-0"

FILTER BUILDING PLAN
SCALE ¼" = 1'-0"

PLATFORM AT EL. 9'-6"
SCALE ½" = 1'-0"

FILTER BUILDING ELEVATION
FILTER & CENTRIFUGE INSTALLATION
SCALE ⅛" = 1'-0" (SIDING NOT SHOWN)

A


100'-0"
6'-0" CLEAR
Ⅽ FENCE
VACUUM SYSTEM (TYP)
FILTRATE RETURN PUMP (TYP) G-109
G-209
G-309
40'-0"
FILTER V-101
FILTER V-201
FILTER V-301
Ⅽ COLLECTION CONVEYOR, T-206
Ⅽ FENCE
TO STACKING AREA
SOLIDS STORAGE AREA
FILTER BUILDING PLAN
SCALE 1/8" = 1'-0"
EL. 22'-0"
EL. 1'-0"
EL. 0'-0"
20'-0"
20'-0"
15'-0"
FILTER BUILDING ELEVATION
FILTER & CENTRIFUGE INSTALLATION
SCALE 1/8" = 1'-0" (SIDING NOT SHOWN)
ISSUED FOR REPORT
I.C.
BECHTEL
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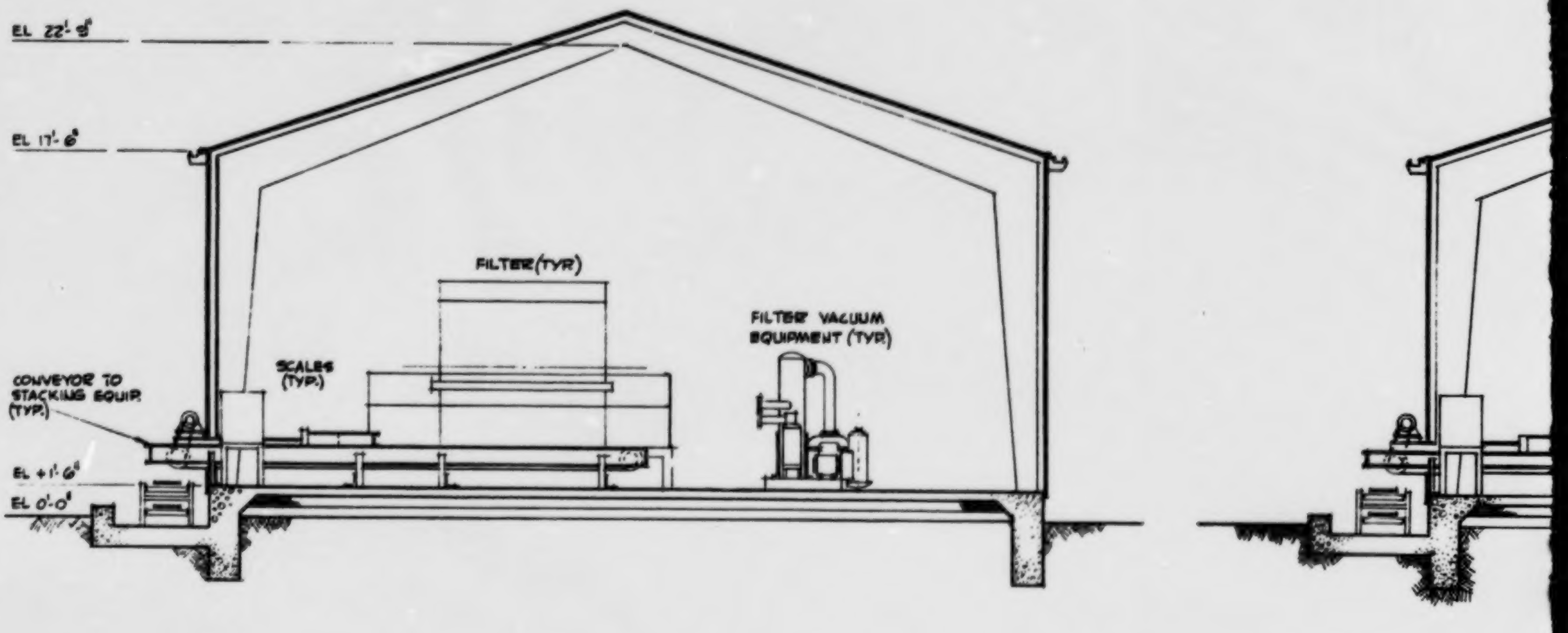
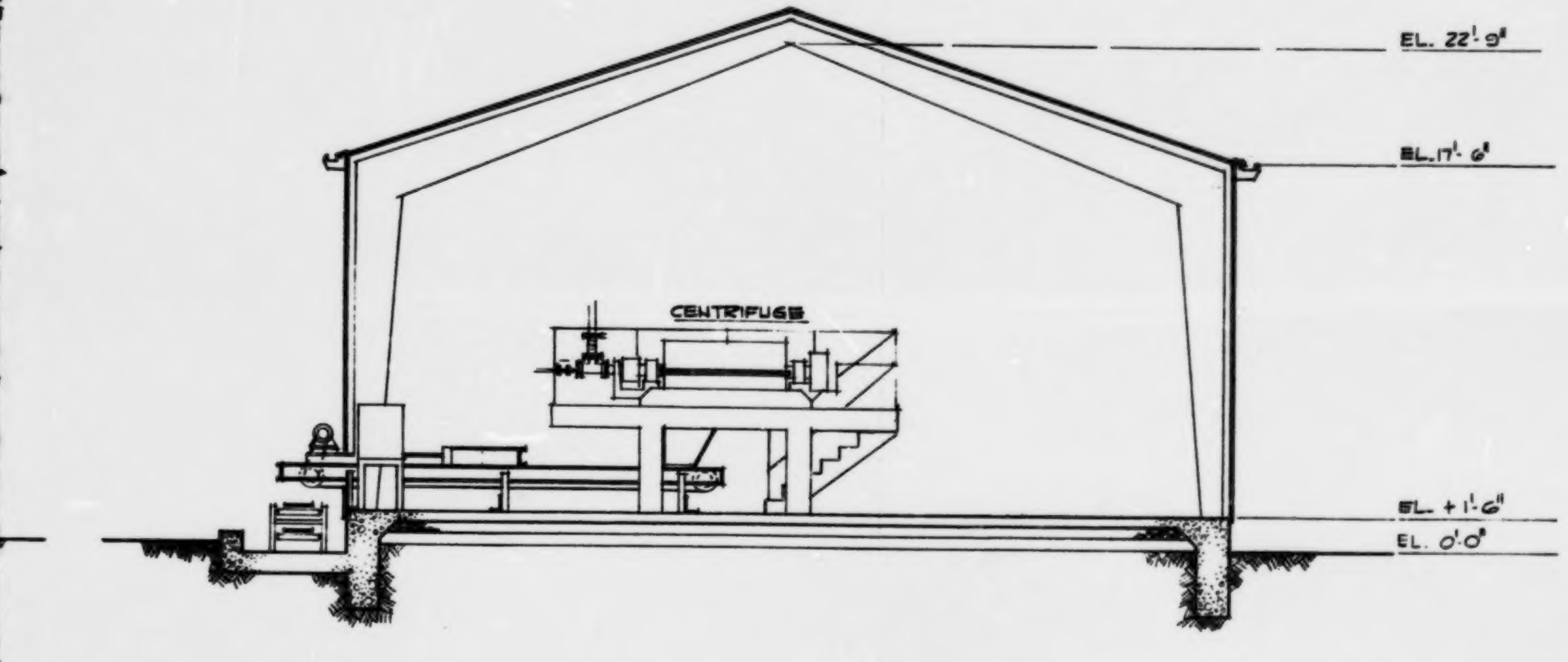
U.A.P.C.A.
ALKALI SCRUBBING TEST FACILITY
DETROIT EDISON, ST. CLAIR PLANT, MICHIGAN
FILTER BUILDING
PLAN &
ELEVATION
6955
Figure 3-15
0

B


EL 22'-9"
EL 17'-6"
FILTER(TYP)
FILTER VACUUM EQUIPMENT (TYP)
SCALES (TYP.)
CONVEYOR TO STACKING EQUIP. (TYP.)
EL +1'-6"
EL 0'-0"

SECTION A-A
(FILTER INSTALLATION)
REF. DWG. FIG. 3-15

A


EL. 22'-9"
EL. 17'-6"
CENTRIFUGE
EL. +1'-6"
EL. 0'-0"

SECTION B-B
CENTRIFUGE INSTALLATION
REF. DWG FIG. 3-15

△								
△								
△								
△								
0	1/17/6-	ISSUED FOR REPORT				C.A.S.	C.R.	

SCALE 1/8" = 1'-0"   DRAWN WEB

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DETROIT EDISON, ST. CLAIR PLANT, MICHIGAN

FILTER BUILDING
SECTION A-A &
SECTION B-B

JOB No.	DRAWING No.	REV
6955	Figure 3-16	0

B

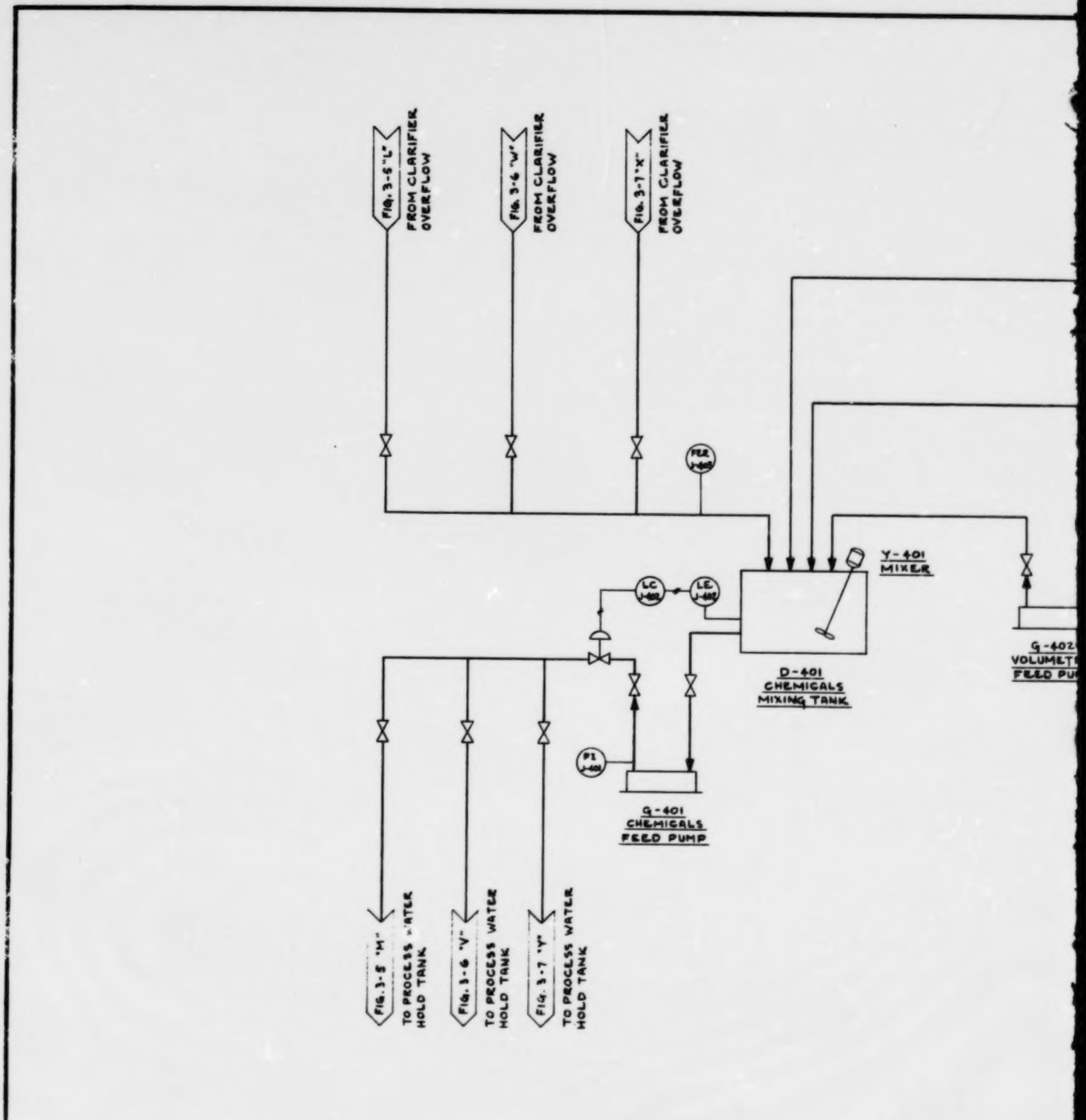
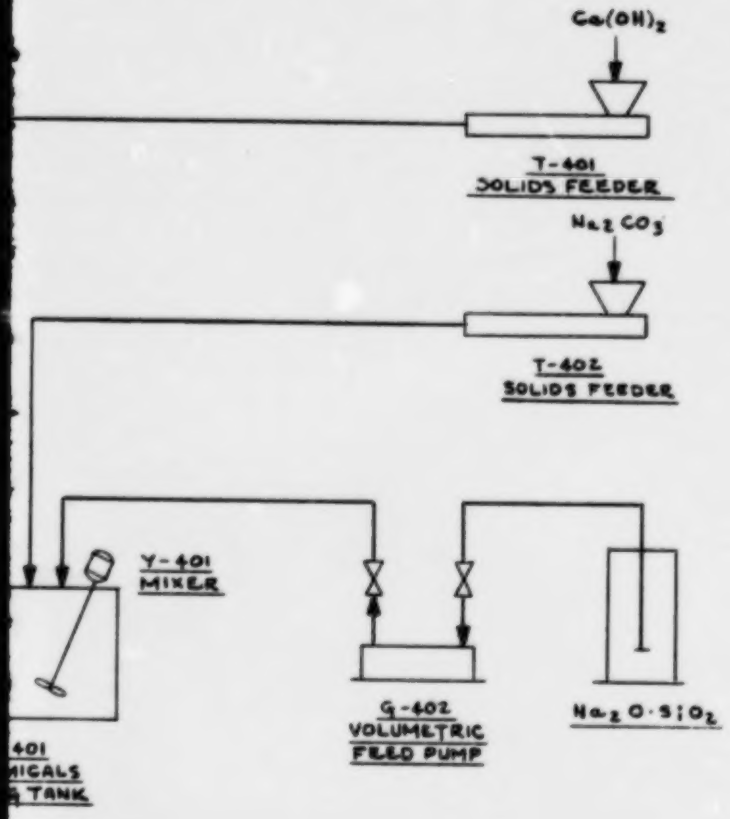


FIG. 3-5 "L"
FROM CLARIFIER OVERFLOW
FIG. 3-6 "W"
FROM CLARIFIER OVERFLOW
FIG. 3-7 "X"
FROM CLARIFIER OVERFLOW
FRR J-402
Y-401
MIXER
LC J-402
LE J-402
D-401
CHEMICALS
MIXING TANK
G-402
VOLUMET
FEED PU
PI J-401
G-401
CHEMICALS
FEED PUMP
FIG. 3-5 "M"
TO PROCESS WATER HOLD TANK
FIG. 3-6 "V"
TO PROCESS WATER HOLD TANK
FIG. 3-7 "Y"
TO PROCESS WATER HOLD TANK

A


$Ca(OH)_2$
T-401
SOLIDS FEEDER
Na_2CO_3
T-402
SOLIDS FEEDER
Y-401
MIXER
401
HICALS
G TANK
G-402
VOLUMETRIC
FEED PUMP
$Na_2O \cdot SiO_2$

NOTE:
FOR GENERAL NOTES, SEE FIGURE 3-5

0	[illegible]	ISSUED FOR REPORT	[illegible]	[illegible]

NONE — J. HING

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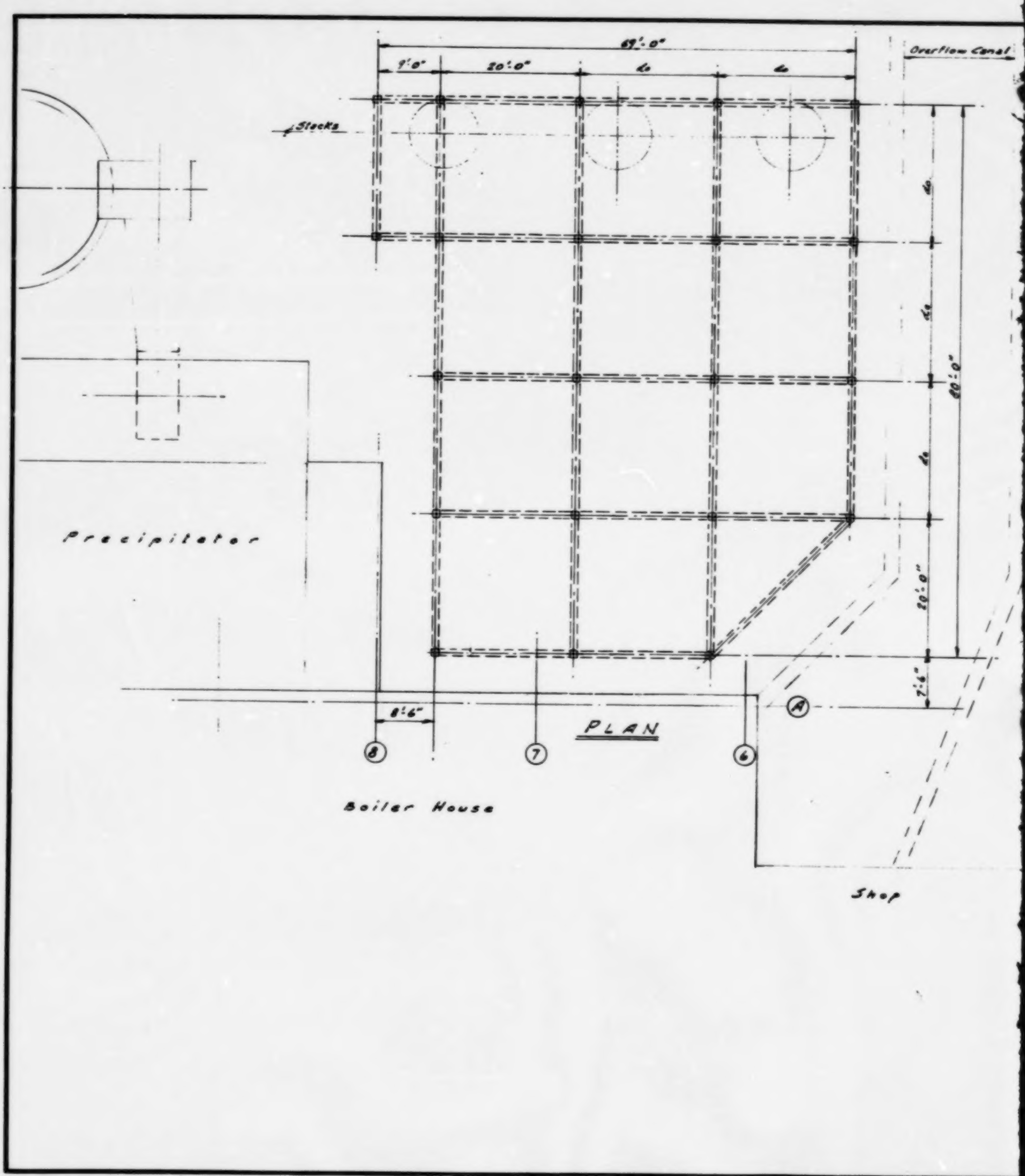
WATER SOFTENING SYSTEM

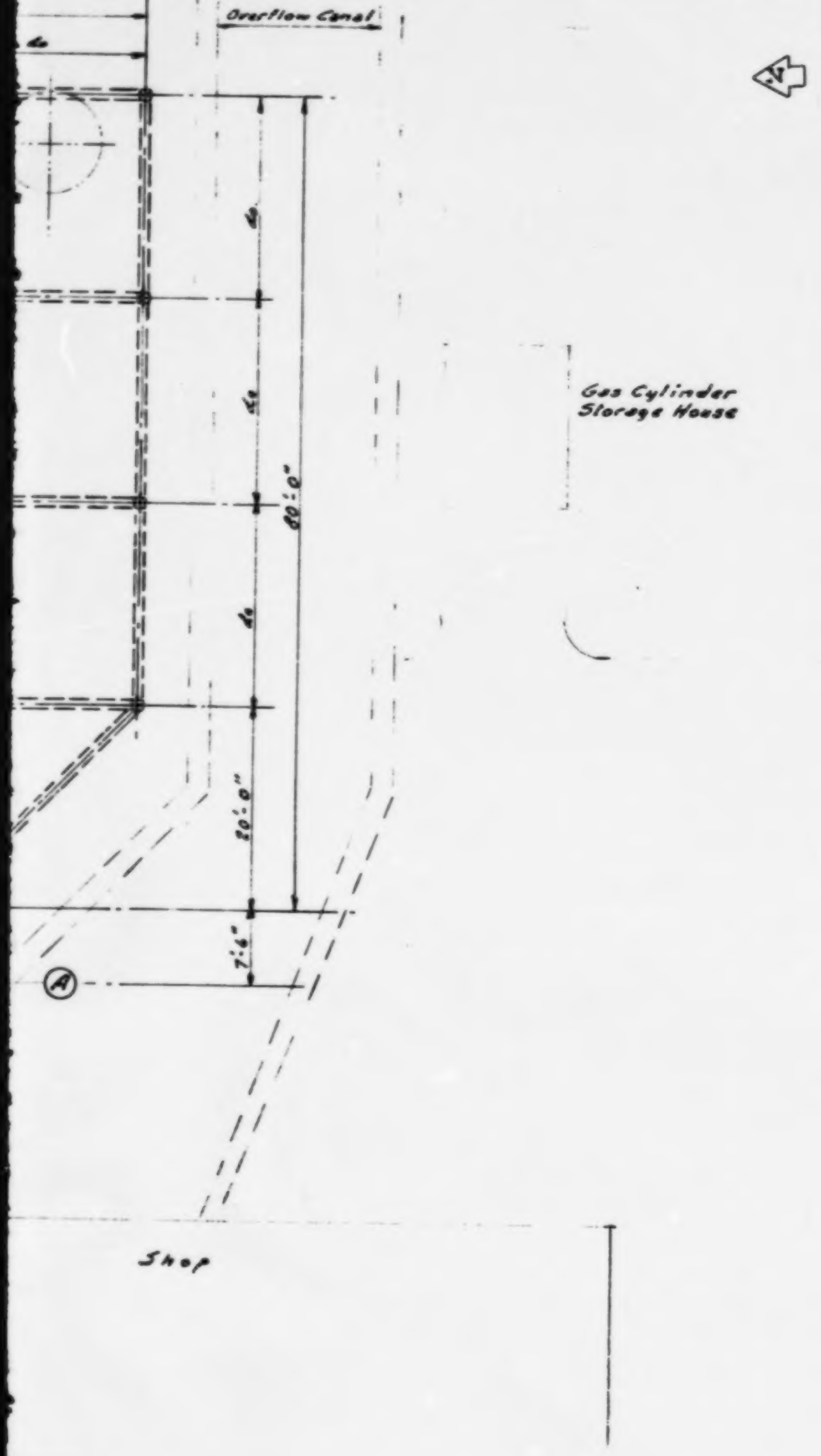
6955	FIGURE 3-17	0

B


69'-0"
9'-0"
20'-0"
do
do
Overflow Canal
Stacks
do
do
do
80'-0"
20'-0"
7'-6"
8'-6"
Precipitator
8
7
6
A
Boiler House
Shop

PLAN

A


Overflow Canal
Gas Cylinder
Storage House
80'-0"
20'-0"
7'-6"
A
Shop

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Scale 1/8" = 1'-0"
Drawn JAP

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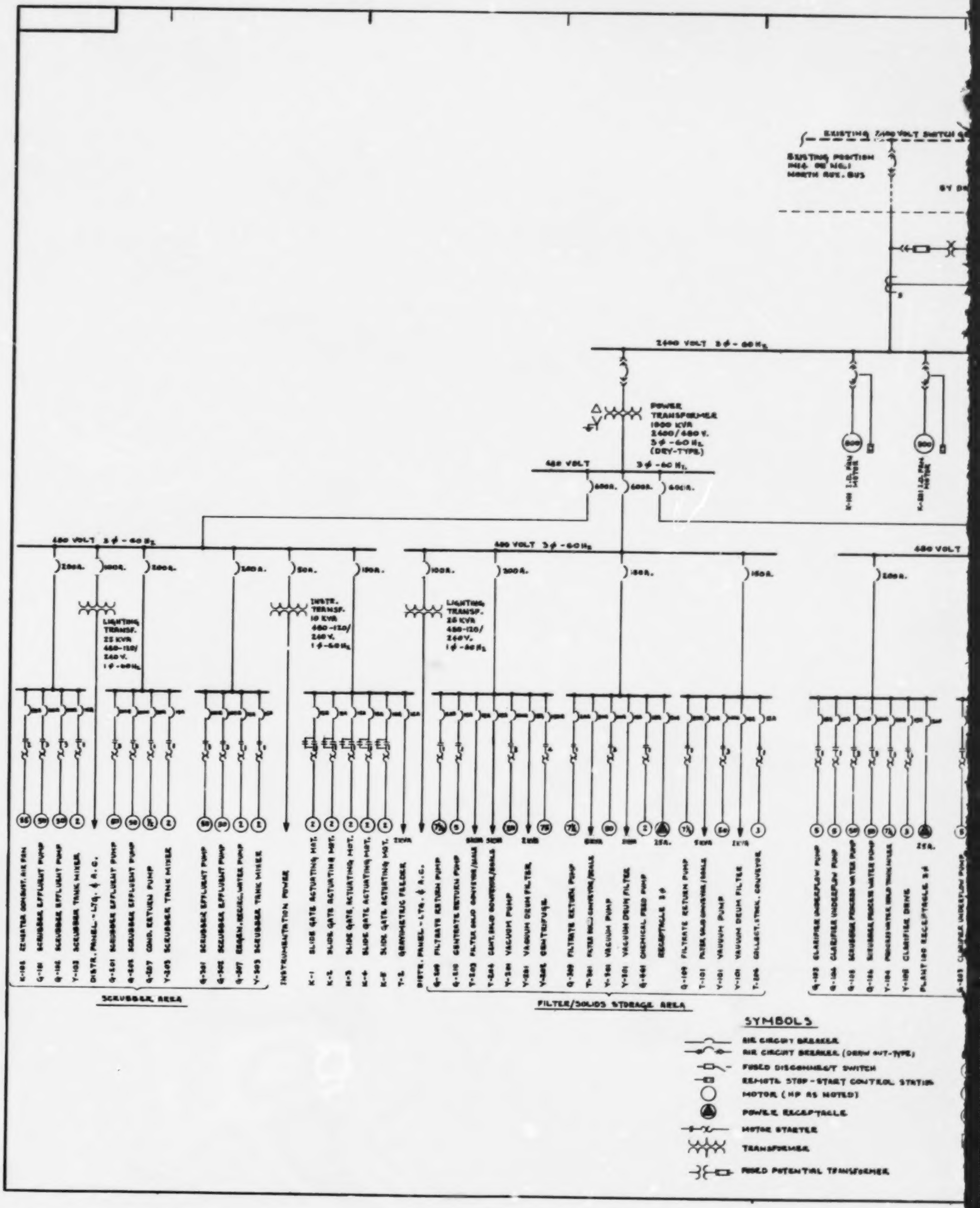
DETROIT EDISON, ST. CLAIR PLANT, MICH.

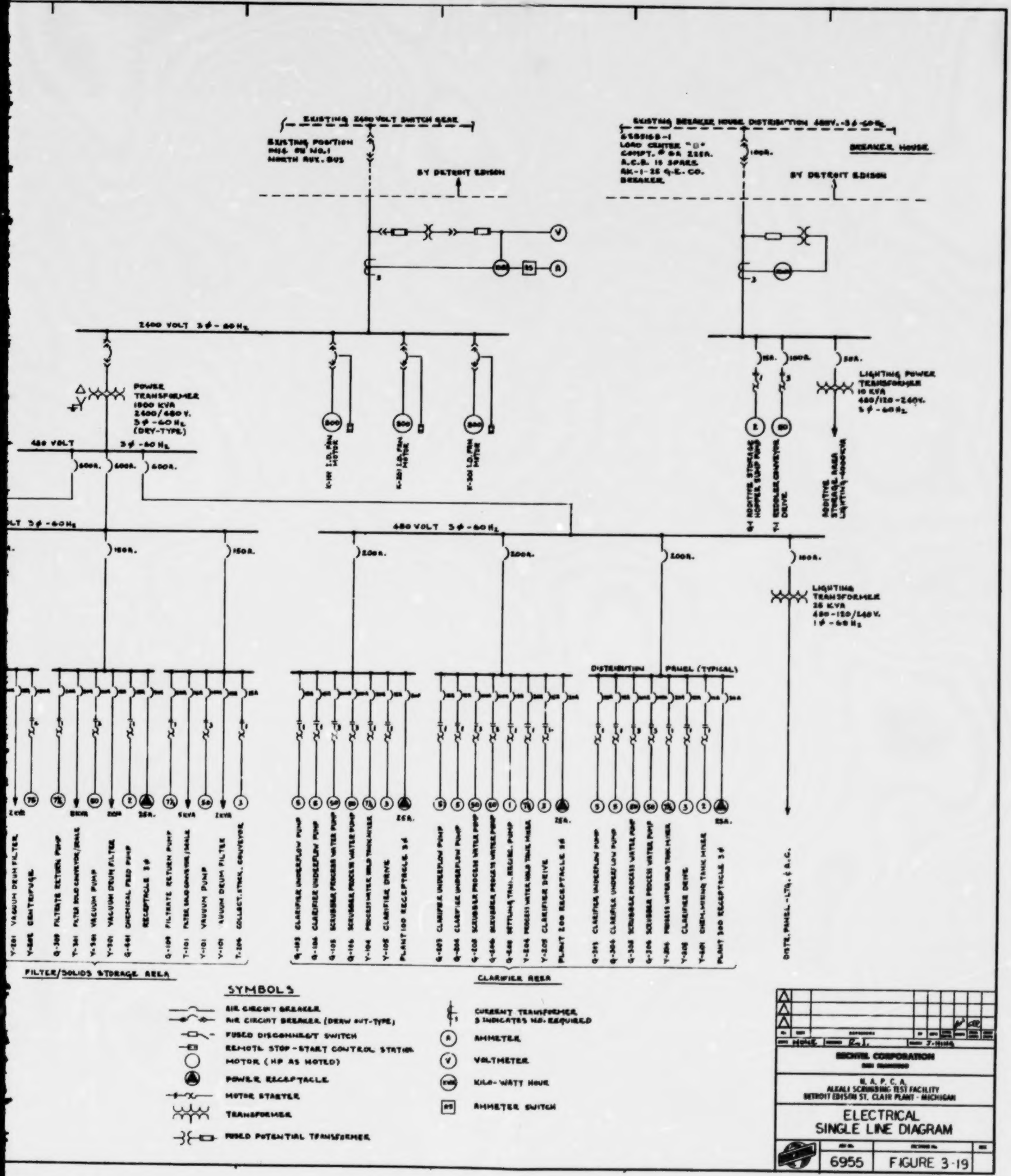
TEST AREA FOUNDATION

6955 Figure 3-18 0

B


EXISTING 2400 VOLT SWITCH G
EXISTING POSITION
INS. ON NO.1
NORTH AUX. BUS
BY O
2400 VOLT 3φ - 60 Hz
POWER TRANSFORMER 1000 KVA 2400/480 V. 3φ - 60 Hz (DRY-TYPE)
800
800
K-101 I.D. FAN MOTOR
K-201 I.D. FAN MOTOR
480 VOLT 3φ - 60 Hz
600A.
600A.
600A.
480 VOLT 3φ - 60 Hz
200A.
100A.
200A.
200A.
50A.
100A.
LIGHTING TRANSF. 25 KVA 480-120/240 V. 1φ - 60 Hz
INSTR. TRANSF. 10 KVA 480-120/240 V. 1φ - 60 Hz
480 VOLT 3φ - 60 Hz
100A.
200A.
150A.
150A.
LIGHTING TRANSF. 25 KVA 480-120/240 V. 1φ - 60 Hz
480 VOLT
200A.
K-101 GENERATOR COMBUST. AIR FAN
G-101 SCRUBBER EFFLUENT PUMP
G-102 SCRUBBER EFFLUENT PUMP
Y-103 SCRUBBER TANK MIXER
DISTR. PANEL - LTG. & R.C.
G-201 SCRUBBER EFFLUENT PUMP
G-202 SCRUBBER EFFLUENT PUMP
G-207 COND. RETURN PUMP
Y-203 SCRUBBER TANK MIXER
G-301 SCRUBBER EFFLUENT PUMP
G-302 SCRUBBER EFFLUENT PUMP
G-307 SCRUBR. RECIRC. WATER PUMP
Y-303 SCRUBBER TANK MIXER
SCRUBBER AREA
INSTRUMENTATION POWER
K-1 SLIDE GATE ACTUATING MOT.
K-2 SLIDE GATE ACTUATING MOT.
K-3 SLIDE GATE ACTUATING MOT.
K-4 SLIDE GATE ACTUATING MOT.
K-5 SLIDE GATE ACTUATING MOT.
T-2 GRAVIMETRIC FEEDER
2 KVA
DISTR. PANEL - LTG. & R.C.
G-309 FILTRATE RETURN PUMP
G-310 CENTRATE RETURN PUMP
T-203 FILTER SOLID CONVEYOR/SEALS
T-204 CENT. SOLID CONVEYOR/SEALS
Y-204 VACUUM PUMP
Y-201 VACUUM DRUM FILTER
Y-205 CENTRIFUGE
G-309 FILTRATE RETURN PUMP
T-301 FILTER SOLID CONVEYOR/SEALS
Y-301 VACUUM PUMP
Y-301 VACUUM DRUM FILTER
G-441 CHEMICAL FEED PUMP
RECEPTACLE 1φ
25A.
G-109 FILTRATE RETURN PUMP
T-101 FILTER SOLID CONVEYOR/SEALS
Y-101 VACUUM PUMP
Y-101 VACUUM DRUM FILTER
T-206 COLLECT. STRK. CONVEYOR
5 KVA
2 KVA
FILTER/SOLIDS STORAGE AREA
G-103 CLARIFIER UNDERFLOW PUMP
G-104 CLARIFIER UNDERFLOW PUMP
G-105 SCRUBBER PROCESS WATER PUMP
G-106 SCRUBBER PROCESS WATER PUMP
Y-104 PROCESS WATER HOLD TANK MIXER
Y-102 CLARIFIER DRIVE
PLANT 100 RECEPTACLE 3φ
25A.
G-203 CLARIFIER UNDERFLOW PUMP
SYMBOLS
AIR CIRCUIT BREAKER
AIR CIRCUIT BREAKER (DRAW OUT-TYPE)
FUSED DISCONNECT SWITCH
REMOTE STOP-START CONTROL STATION
MOTOR (HP AS NOTED)
POWER RECEPTACLE
MOTOR STARTER
TRANSFORMER
FUSED POTENTIAL TRANSFORMER

A


EXISTING 2400 VOLT SWITCH GEAR
EXISTING POSITION
H14 ON NO.1
NORTH AUX. BUS
BY DETROIT EDISON
EXISTING BREAKER HOUSE DISTRIBUTION 480V.-3Ø-60Hz
6585168-1
LOAD CENTER "B"
COMPT. # 6A 225A.
A.C.B. 15 SPARE
AK-1-25 G.E. CO.
BREAKER
100A.
BREAKER HOUSE
BY DETROIT EDISON
V
A
KWH
AS
3
2400 VOLT 3Ø-60Hz
POWER
TRANSFORMER
1000 KVA
2400/480 V.
3Ø-60Hz
(DRY-TYPE)
800
K-101 I.D. FAN MOTOR
800
K-201 I.D. FAN MOTOR
800
K-301 I.D. FAN MOTOR
15A.
100A.
50A.
2
50
G-1 ADDITIVE STORAGE HOPPER SUMP PUMP
T-1 RECYCLER CONVEYOR DRIVE
LIGHTING POWER
TRANSFORMER
10 KVA
480/120-240V.
3Ø-60Hz
ADDITIVE STORAGE AREA LIGHTING-10KVA
480 VOLT 3Ø-60Hz
600A.
600A.
600A.
VOLT 3Ø-60Hz
150A.
150A.
480 VOLT 3Ø-60Hz
200A.
200A.
200A.
100A.
LIGHTING
TRANSFORMER
25 KVA
480-120/240V.
1Ø-60Hz
DISTRIBUTION PANEL (TYPICAL)
2KW
75
7½
8KVA
80
2KW
2
25A.
7½
5KVA
50
2KVA
3
Y-201 VACUUM DRUM FILTER
Y-202 CENTRIFUGE
G-309 FILTRATE RETURN PUMP
T-301 FILTER SOLID CONVEYOR/SCALE
Y-301 VACUUM PUMP
Y-301 VACUUM DRUM FILTER
G-401 CHEMICAL FEED PUMP
RECEPTACLE 3Ø
G-109 FILTRATE RETURN PUMP
T-101 FILTER SOLID CONVEYOR/SCALE
Y-101 VACUUM PUMP
Y-101 VACUUM DRUM FILTER
T-206 COLLECT. STACK. CONVEYOR
FILTER/SOLIDS STORAGE AREA
5
5
50
80
7½
3
25A.
G-103 CLARIFIER UNDERFLOW PUMP
G-104 CLARIFIER UNDERFLOW PUMP
G-105 SCRUBBER PROCESS WATER PUMP
G-106 SCRUBBER PROCESS WATER PUMP
Y-104 PROCESS WATER HOLD TANK MIXER
Y-105 CLARIFIER DRIVE
PLANT 100 RECEPTACLE 3Ø
5
5
50
50
1
7½
3
25A.
G-203 CLARIFIER UNDERFLOW PUMP
G-204 CLARIFIER UNDERFLOW PUMP
G-205 SCRUBBER PROCESS WATER PUMP
G-206 SCRUBBER PROCESS WATER PUMP
G-208 SETTLING TANK RECIRC. PUMP
Y-204 PROCESS WATER HOLD TANK MIXER
Y-205 CLARIFIER DRIVE
PLANT 200 RECEPTACLE 3Ø
5
5
80
50
7½
3
2
25A.
G-303 CLARIFIER UNDERFLOW PUMP
G-304 CLARIFIER UNDERFLOW PUMP
G-305 SCRUBBER PROCESS WATER PUMP
G-306 SCRUBBER PROCESS WATER PUMP
Y-304 PROCESS WATER HOLD TANK MIXER
Y-305 CLARIFIER DRIVE
Y-401 CHEM. MIXING TANK MIXER
PLANT 300 RECEPTACLE 3Ø
DISTR. PANEL-LTG. & R.C.
CLARIFIER AREA
SYMBOLS
AIR CIRCUIT BREAKER
AIR CIRCUIT BREAKER (DRAW OUT-TYPE)
FUSED DISCONNECT SWITCH
REMOTE STOP-START CONTROL STATION
MOTOR (HP AS NOTED)
POWER RECEPTACLE
MOTOR STARTER
TRANSFORMER
FUSED POTENTIAL TRANSFORMER
CURRENT TRANSFORMER
3 INDICATES NO. REQUIRED
A AMMETER
V VOLTMETER
KWH KILO-WATT HOUR
AS AMMETER SWITCH

NONE
E.J.
J. HING

BECHTEL CORPORATION
SAN FRANCISCO

N. A. P. C. A.
ALKALI SCRUBBING TEST FACILITY
DETROIT EDISON ST. CLAIR PLANT - MICHIGAN

ELECTRICAL
SINGLE LINE DIAGRAM

6955 FIGURE 3-19

B

Section 4

PHASE II PLAN AND SCHEDULE

4.1 GENERAL SCOPE

Phase II of the limestone scrubbing program will cover engineering and construction of the test facilities at Detroit Edison Company's St. Clair Power Plant. Based on the preliminary design work presented in this report, Phase II will consist of detailed engineering and preparation of specifications. Bid evaluation and purchasing of equipment will follow. Equipment delivered at the site will be erected and piping, wiring, and instrumentation installed. Phase II will conclude with start-up of the equipment.

4.2 ASSUMPTIONS

In preparing the construction schedule and budget cost estimate presented in Section 15, the following assumptions were made:

- An engineer-construction firm will act as prime contractor for the government.
- The engineer-constructor will perform all detailed engineering.
- Construction will be performed partly by the engineer-constructor's own forces and partly by local subcontractors.
- For the duration of the construction phase, the engineer-constructor will assign a Superintendent to be at the job site. The Superintendent will be supported by technical personnel as required.

- The engineer-constructor will be responsible for purchasing, inspection, and expediting.
- The engineer-constructor will be responsible for control of cost, schedule and quality of work.
- NAPCA will exercise supervision by reviewing and approving specifications, bid evaluations, and purchase orders.
- After construction is completed, the engineer-constructor will assign a Start-up Engineer who will start up and check the functioning of equipment.
- The engineer-constructor will be responsible for liaison with Detroit Edison Company and will ensure that construction work causes minimum interference with normal operation of the boiler plant.
- The engineer-constructor will cooperate closely with the scrubber manufacturers to ensure that the experimental equipment is designed, erected, and operated in an effective and economical manner according to their recommendations.

4.3 TEST PROGRAM

The test program, discussed in Section 14, will be further refined and details of methods for testing and acquiring data will be worked out.

In order to prepare for the prompt evaluation of the test data, a computer program will be prepared during Phase II. The program will take input from the magnetic tape of the data acquisition system and will perform the repetitive calculations required for optimizing the scrubber process flow data.

4.4 CONSTRUCTION SCHEDULE

A tentative schedule has been prepared to cover the construction-related activities of the engineer-constructor during Phase II. The most critical timing within the construction schedule pertains to activities that must be performed when Boiler 1 is taken out of service.

Detroit Edison Company has stated that this unit is due for an approximately two-week maintenance shutdown during December 1969. It is not believed that this time will be adequate to perform all the test program tie-ins requiring boiler shutdown. Following is a list of the critical activities that must be performed while the boiler is shut down:

- Installation of partition walls inside coal bunker
- Installation of new discharge chute for limestone
- Installation of gate assemblies into coal and limestone discharge chutes
- Installation of gravimetric feeder
- Installation of feed piping to gravimetric feeder and pulverizer
- Removal of connecting flue gas duct outside of boiler house adjacent to dust precipitator inlet
- Installation of five slide-gate assemblies
- Installation of new bypass duct
- Installation of main shutoff damper
- Installation of new control panel in unit control room 1 for new ID fans and draft control dampers

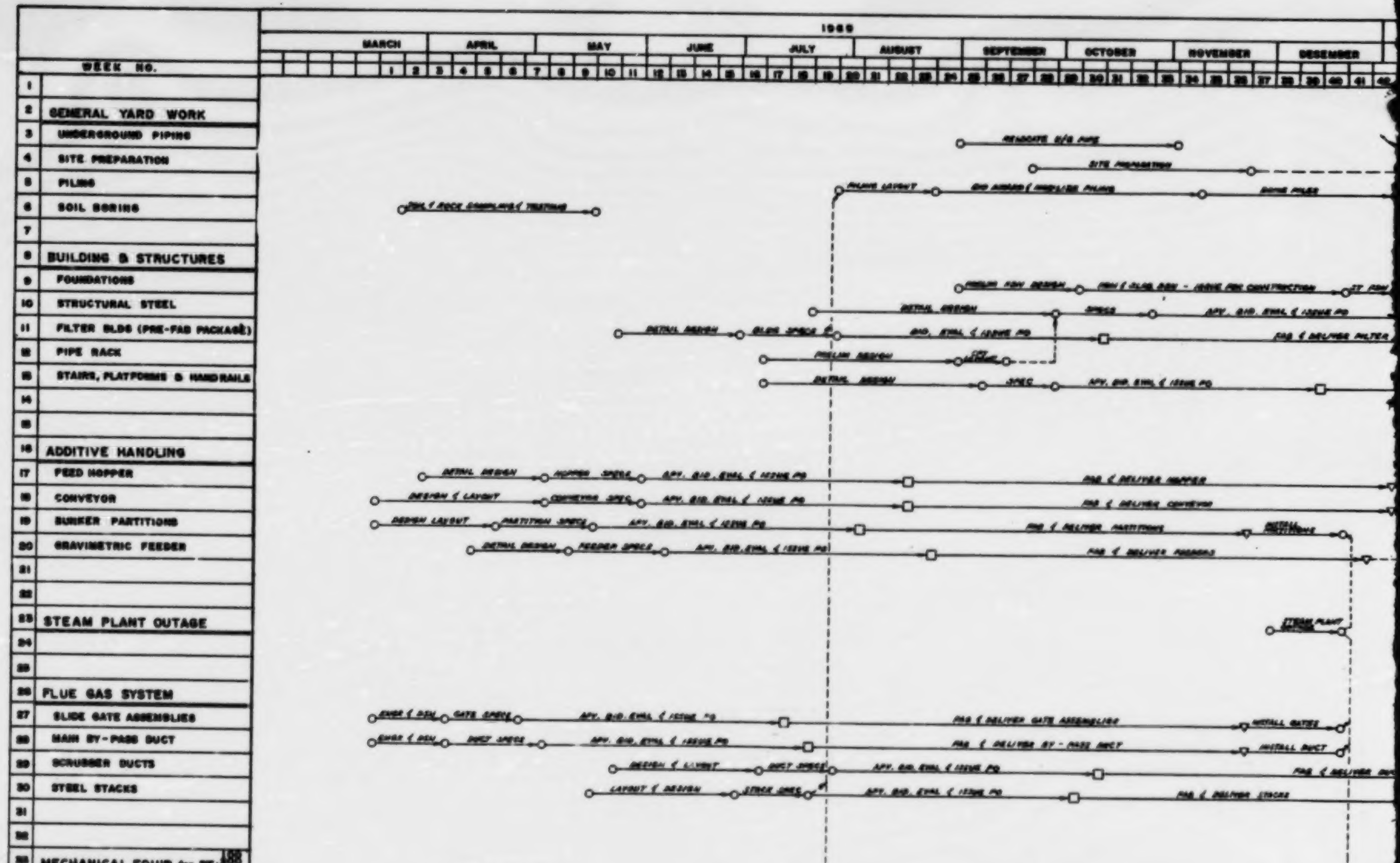
Even with meticulous preparation and around-the-clock construction work, the construction activities described above will require at least three weeks. The construction schedule was prepared with this requirement in mind.

A three-week approval period is allowed for after the specifications are completed, and another three weeks for NAPCA approval of bid evaluations and purchase orders.

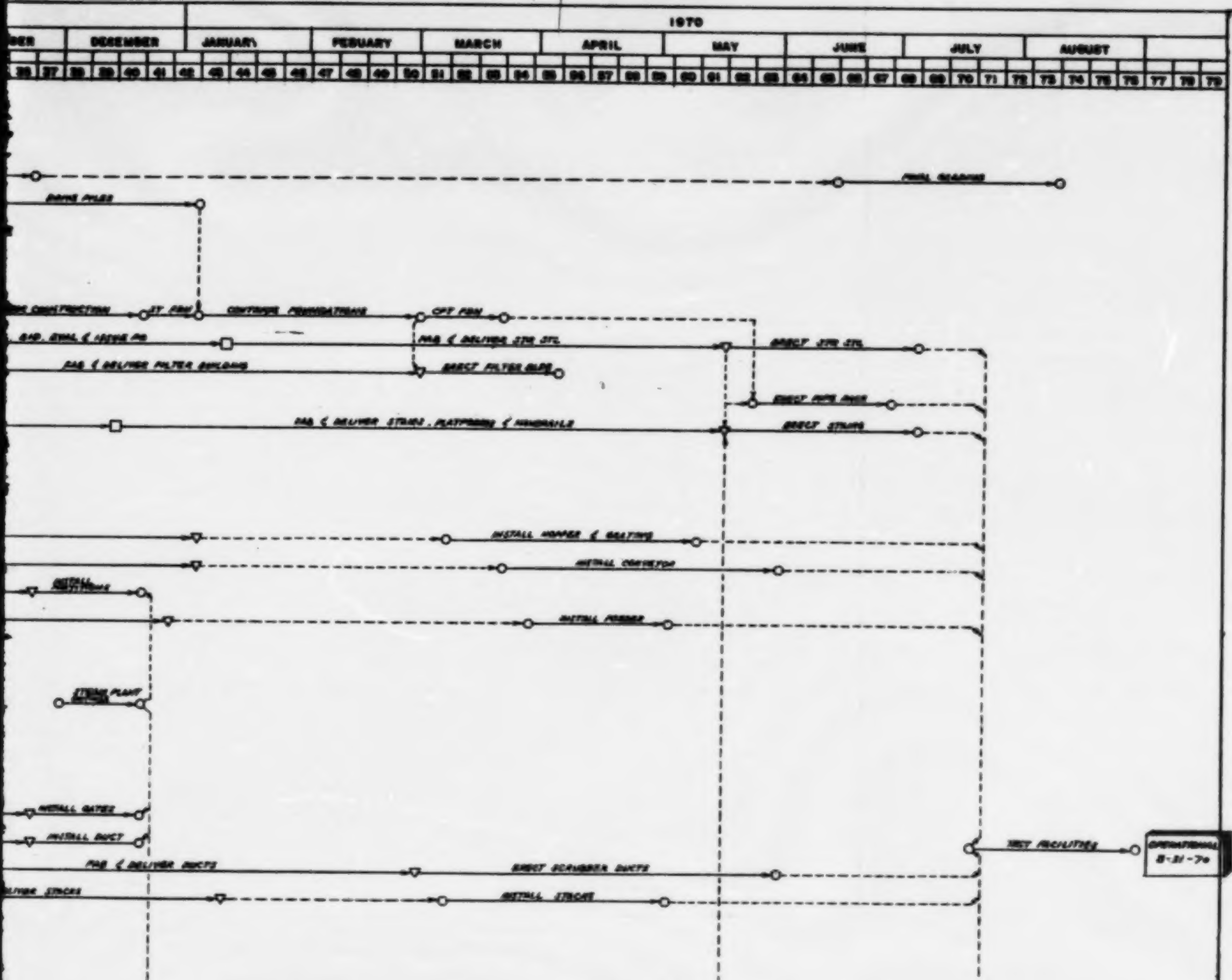
Figure 4-1 indicates the construction schedule. Lead times are based on current purchasing experience.

During Phase II, careful planning must precede the installation of the coal bunker partition walls. The difficulties to be dealt with when planning the proper procedure are as follows:

- During installation of the partition walls, the two tripper conveyors above the bunker will be operating most of the time, as they supply coal to the six other units of the power plant. This means that the prefabricated elements of the partition walls cannot be brought in from the conveyor gallery. A hole will have to be cut in the wall of the bunker large enough to accommodate the biggest prefabricated piece of the partition walls.
- The coal bunker area is interconnected with the bunkers of adjacent boilers. Even though the bunker will be emptied before partitions are installed, the bunker space will be filled with a coal dust and air mixture, which is potentially explosive. Before any welding is attempted, therefore, adequate separation of the bunker space must be provided and air blown into the working space so that coal dust accumulation will be prevented.
- Safety precautions must be taken that no coal is inadvertently discharged into the bunker space while construction work is going on inside.


1969
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
WEEK NO.
GENERAL YARD WORK
UNDERGROUND PIPING
SITE PREPARATION
PILING
SOIL BORING
BUILDING & STRUCTURES
FOUNDATIONS
STRUCTURAL STEEL
FILTER BLDG (PRE-FAB PACKAGE)
PIPE RACK
STAIRS, PLATFORMS & HANDRAILS
ADDITIVE HANDLING
FEED HOPPER
CONVEYOR
BUNKER PARTITIONS
GRAVIMETRIC FEEDER
STEAM PLANT OUTAGE
FLUE GAS SYSTEM
SLIDE GATE ASSEMBLIES
MAIN BY-PASS DUCT
SCRUBBER DUCTS
STEEL STACKS
MECHANICAL EQUIP for PT.
SCRUBBERS
CLARIFIERS
VACUUM FILTERS
CENTRIFUGE
REHEATERS
I.D. FANS
LIMITORQUE OPERATOR
MULTI-LEAF DAMPERS
MISC. PUMPS
MISC TANKS
PIPING
SOLIDS CONVEYORS
ELECTRICAL SYSTEM
SWITCHGEAR 2400V
POWER TRANSFORMERS
DISTRIBUTION PANELS 480V
CABLE & WIRE
YARD LIGHTING
INSTRUMENTATION
BOILER INSTRUMENTATION
PROCESS INSTRUMENTATION
DETAIL DESIGN
SPECS
APV. BID. EVAL. & ISSUE PO
FAB & DELIVER

A


1970
DECEMBER
JANUARY
FEBUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
FINAL GRADING
DRIVE PILES
CONSTRUCTION
ST FDN
CONTINUE FOUNDATIONS
CPT FDN
BID, EVAL & ISSUE PO
FAB & DELIVER STR STL
ERECT STR STL
FAB & DELIVER FILTER BUILDING
ERECT FILTER BLDG
ERECT PIPE RACK
FAB & DELIVER STAIRS, PLATFORMS & HANDRAILS
ERECT STAIRS
INSTALL HOPPER & GRATING
INSTALL CONVEYOR
INSTALL FEEDER
STEAM PLANT
INSTALL GATES
INSTALL DUCT
FAB & DELIVER DUCTS
ERECT SCRUBBER DUCTS
TEST FACILITIES
OPERATIONAL 8-31-70
INSTALL STACKS
FAB & DELIVER SCRUBBERS
ERECT SCRUBBERS
FAB & DELIVER CLARIFIERS
ERECT CLARIFIERS
FAB & DELIVER VACUUM FILTERS
INSTALL FILTERS
& DELIVER CENTRIFUGE
INSTALL CENTRIFUGE
FAB & DELIVER REHEATERS
INSTALL REHEATERS
FAB & DELIVER FANS
INSTALL FANS
INSTALL DAMPERS
FAB & DELIVER PUMPS
INSTALL PUMPS
TANKS
ERECT TANKS
& ISSUE PO
FAB & DELIVER PIPING
INSTALL PIPING
CONVEYORS
INSTALL CONVEYOR
FAB & DELIVER SWITCHGEAR
INSTALL SWITCHGEAR
ENERGIZE & TEST
FAB & DELIVER TRANSFORMERS
INSTALL TRANSFORMERS
FAB & DELIVER PANELS
INSTALL PANELS
FAB & DELIVER WIRE & CABLE
INSTALL WIRE & CABLE
INSTALL YARD LIGHTING
INSTALL A.L.R.
FAB & DELIVER PROCESS INSTRUMENTATION
CALIBRATE & TEST INSTRUMENTATION
REMARK
LEGEND
O—O ACTIVITY
□ ISSUE PURCHASE ORDER
▽ EQUIPMENT AT SITE

GENERAL REVIEW

DRUEKE L. LEE

BECHTEL
SAN FRANCISCO

PROJECT SUMMARY SCHEDULE

N.A.P.C.A.
ALKALI SCRUBBING TEST FACILITY
DETROIT EDISON ST. CLAIRE PLANT - MICHIGAN

6085 FIGURE 4-1 /

B

Section 5

PROCESS REVIEW

When coal or oil burns in the furnace of a steam generator, nearly all the sulfur content of the fuel is converted to sulfur dioxide. Studies show that from 1 to 3 percent of this sulfur dioxide is converted to sulfur trioxide, probably through catalysis on high-temperature surfaces. The process to be described removes these sulfur oxides and also particulates by scrubbing the flue gas with an alkaline solution. The scrubbing chemical is supplied to the system by injecting a solid additive, such as dolomite or limestone, directly into the boiler furnace. Figure 5-1 is a basic flow diagram for the process.

The alkali additive is pulverized to 80 percent minus 200 mesh and injected into a high-temperature section of the boiler. Calcium Oxide and Magnesium Oxide (if dolomite is used), which result from calcination in the boiler, react with some of the sulfur oxides in the flue gas to form calcium sulfite, calcium sulfate, magnesium sulfite, and magnesium sulfate.

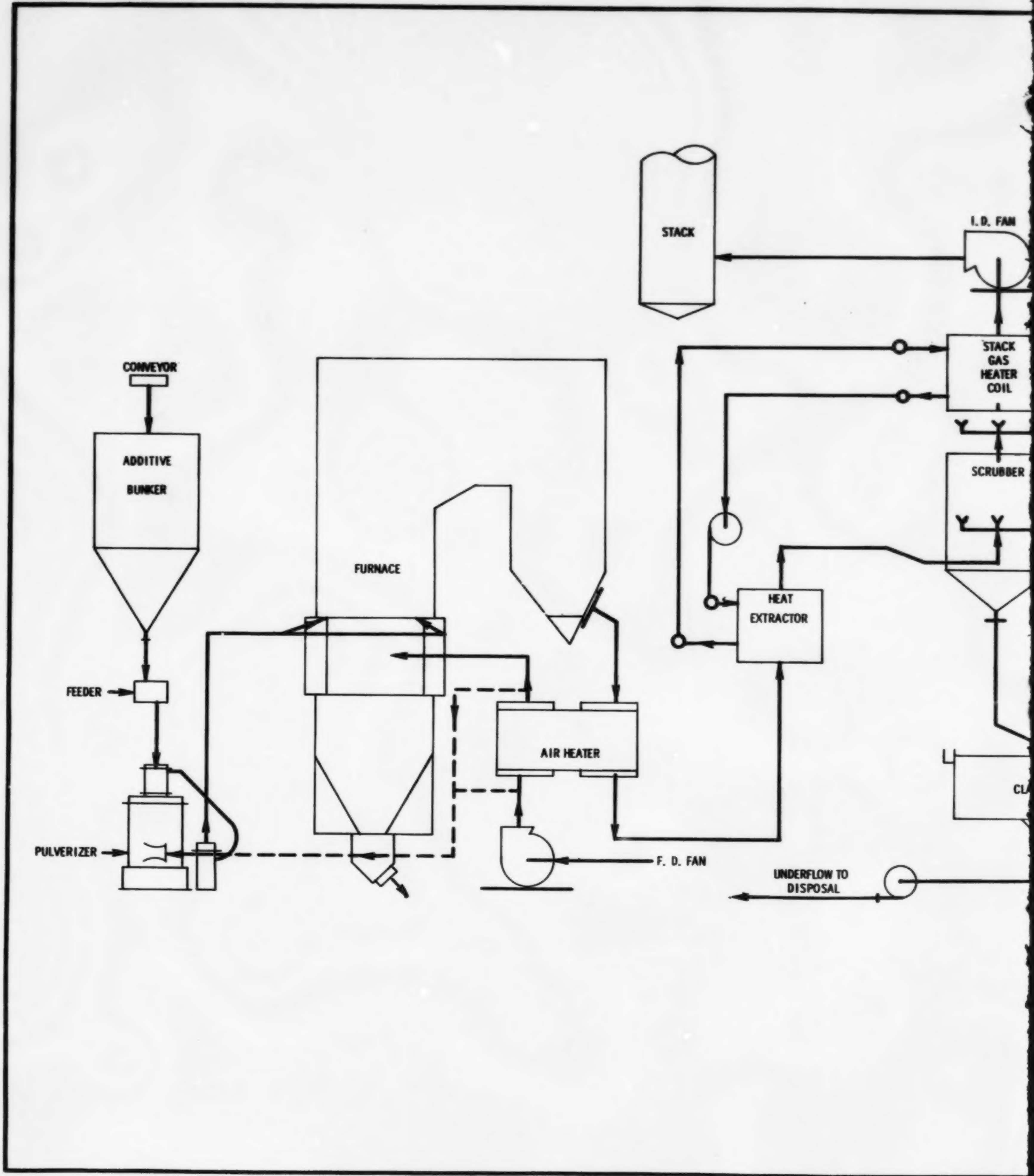
Recent pilot plant data indicate that the quantity of additive to be fed to the furnace should normally be 105 to 120 percent of the stoichiometric requirement to react completely with all of the sulfur dioxide. With this quantity of additive, practically no sulfur trioxide is emitted from the stack. Fixation of perhaps 20 percent of the sulfur dioxide to form calcium sulfite should occur in the boiler proper. Recent reports from Kansas Power and Light Company's Lawrence Station indicate a higher degree of fixation.

Flue gas leaves the boiler section containing sulfur dioxide, fly-ash from the fuel, and the solid compounds (CaO, $CaSO_3$, $CaSO_4$, MgO, $MgSO_3$, $MgSO_4$) formed in the furnace reactions. Gas and solids pass through a conventional air preheater and a set of water sprays to saturate the gas before it enters the scrubber. The scrubber removes the remaining sulfur oxides and particulates. The clean gas, saturated with water, passes through a reheater before discharge to the stack. Local atmospheric conditions determine the level of reheat required to avoid formation of a water vapor plume.

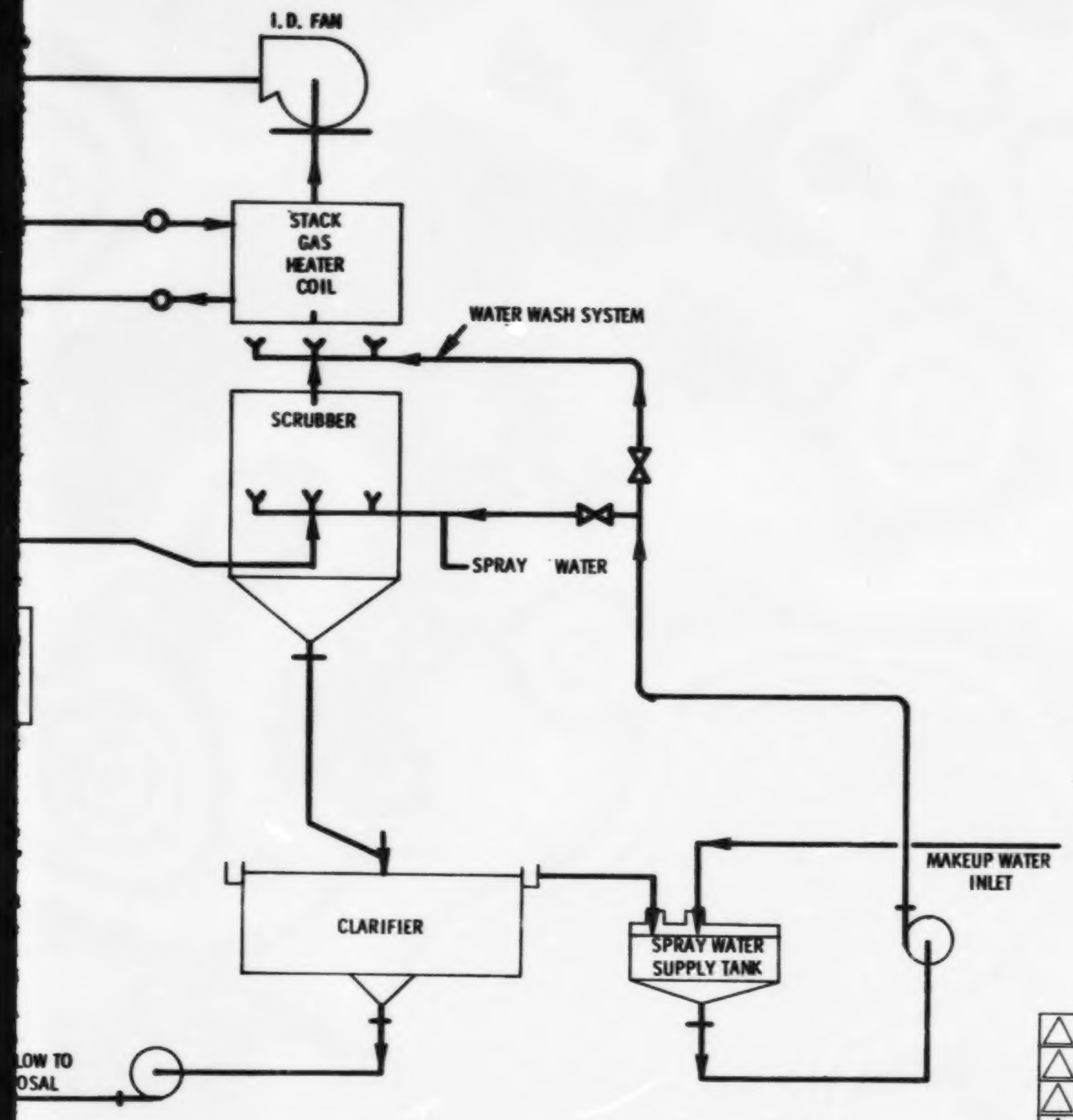
Within the scrubber solution circuit, calcium and magnesium oxides that have not previously reacted with sulfur oxides in the furnace now form hydroxides. These hydroxides then react with the sulfur dioxide absorbed in the water to form calcium sulfite and magnesium sulfite. Fractions of these sulfites are oxidized to sulfates. Calcium sulfite, calcium sulfate, and magnesium sulfite are only slightly soluble in water and are mostly precipitated. Magnesium sulfate, however, is quite soluble and will precipitate only if the recycle scrubbing solution builds up to saturation.

The discharge from the bottom of the scrubber is a liquid-solid mixture containing precipitated sulfur compounds and fly-ash. The solution is decanted from the solids in a clarifier and recycled to the scrubber. Underflow from the clarifier may require further dewatering before disposal. Makeup-water requirements for the system are set by losses occurring from evaporation and carry-over in the scrubber, solids disposal, and miscellaneous leakage.

Table 5-2 at the end of this section is an effort to summarize what is known or not known about the alkali injection-scrubbing process and the significance of this data or knowledge. It further lists what needs to be done in the text program to acquire the data that is not known. This


STACK
I. D. FAN
STACK
GAS
HEATER
COIL
CONVEYOR
ADDITIVE
BUNKER
SCRUBBER
FURNACE
HEAT
EXTRACTOR
FEEDER
AIR HEATER
CL
PULVERIZER
F. D. FAN
UNDERFLOW TO
DISPOSAL

A


I. D. FAN
STACK GAS HEATER COIL
WATER WASH SYSTEM
SCRUBBER
SPRAY WATER
CLARIFIER
SPRAY WATER SUPPLY TANK
MAKEUP WATER INLET
LOW TO
OSAL

DRAWN B. G. HALL

BECHTEL
SAN FRANCISCO

N. A. P. C. A.
ALKALI SCRUBBING TEST FACILITY
DETROIT EDISON ST. CLAIR PLANT - MICHIGAN

PROCESS FLOW SCHEME
AIR POLLUTION CONTROL SYSTEM
ALKALI SOLIDS INJECTION-WET SCRUBBING

JOB No.	DRAWING No.	REV.
6955	FIGURE 5 - 1	0

B

summary resulted from literature study, discussions with equipment vendors, field trips to the Meramec facility of Union Electric Company, and from Bechtel's concepts of the proposed test facility. The table does not describe scrubber performance, since this is discussed in detail in Section 6.

5.1 DEVELOPMENT AND STATUS OF PROCESS

The alkali injection-wet scrubbing concept for cleaning flue gas evolved from technologies previously developed. Alkaline scrubbing, on a commercial scale, had been used to remove sulfur oxides and dust from flue gas before 1940.[1, 2] Alkali solids are sometimes injected into the boiler, primarily for tube-corrosion control. Research programs are actively investigating SO_2 removal by alkali injection into the boiler. The following discussion briefly mentions this related technology and defines the current status of alkali injection-wet scrubbing.

5.1.1 Alkaline Scrubbing

The first process for washing flue gas at power stations was an alkaline scrubbing system developed by the London Power Company[1] about 1931 for Battersea Station on the Thames River. Wash water taken from the river contained about four-fifths of the alkalinity needed to neutralize the sulfur dioxide in the flue gas. Chalk ($CaCO_3$) addition made up the remaining alkalinity requirement. Calcium sulfate produced in the process was discharged into the river.

Another early (1933) alkaline scrubbing system, the Howden-I. C. I. Cyclic Lime Process,[2] recycled scrubbing solution after removing calcium sulfite and calcium sulfate. Alkalinity was supplied by chalk or lime. The calcium sulfate sludge had to be disposed of by other means than discharge into a river. Although the process removed

90 percent of the sulfur dioxide in the gas, it did not survive for economic reasons — investment, operating, maintenance, and waste-disposal costs all being high. Both the Howden and Battersea processes used a wood-slat grid packing for the sulfur dioxide absorbers.

In 1962, Mitsubishi Heavy Industries, Ltd., Japan, constructed a pilot plant to study lime scrubbing. They have applied the system to scrubbing tail gas from a sulfuric acid plant. Mitsubishi now offers the process for commercial application.[3] The system is similar to the Howden-I.C.I. process, but produces a gypsum product that can be marketed in Japan. The Japanese development program tested three types of absorption devices on oil-fired-boiler flue gas: grid-packed tower, venturi scrubber, and a cross-flow absorber. Mitsubishi concluded that the grid-packed tower is most suitable for handling the lime slurry.

In 1968, Bahco Company[4,5] of Sweden announced a lime scrubbing system of commercial scale that uses a two-stage venturi scrubber. Bahco calims high sulfur dioxide removal efficiency — 98.5 percent with 3.5-percent sulfur in the fuel oil.

5.1.2 Alkali Solids Injection

An attractive economic potential exists for a process that would remove sulfur oxides by fixation with an alkali solid injected into the boiler followed by dry removal, without wet scrubbing. Research programs in Germany,[6, 7, 8, 9, 10, 11, 12] the United States,[13, 14, 15, 16] and Japan[17, 18] are actively pursuing this concept. Many of the important parameters such as temperature, residence time, and particle size that affect the gas-solids reactions have been identified, but the system has not been optimized.

A design study by TVA[15] indicates only 20- to 25-percent removal of sulfur oxides with injection of the stoichiometric quantity. As much as 3.5 times the stoichiometric quantity is required to achieve high sulfur oxides removal. The TVA study assumed that twice the stoichiometric quantity with 3.5-percent-sulfur coal would probably result in the maximum dust loading that could be tolerated. This amount of additive would probably remove no more than 50 percent of the sulfur oxides.

5.1.3 Alkali Solids Injection - Wet Scrubbing

Combination of alkali solids injection with wet scrubbing overcomes many of the disadvantages of the separate steps. Some of the more important advantages of the combined techniques are:

- Sulfur dioxide removal efficiency should reach 80 percent, with approximately the stoichiometric amount of additive.
- The presence of alkali oxides within the boiler reduces corrosion.
- The scrubber serves as a dust collector, which reduces some of the investment charge against sulfur dioxide removal.

Wisconsin Electric Power Company[14] has conducted a pilot-plant program involving separate testing of limestone injection and alkaline wet scrubbing. The wet-scrubbing pilot plant was installed on Oak Creek Unit 1, a 120-Mw, pulverized-coal-fired boiler. Tests of limestone additive mixed with coal were conducted at Port Washington Units 1 and 2, each of 80 Mw. The WEPCO facility did not combine limestone injection with wet-scrubbing.

Combustion Engineering, Inc.[19, 20, 21] has developed this process to commercial status. Pilot-plant work was conducted with Detroit Edison Company at their St. Clair power station. The pilot unit ran on a portion

(1 percent, or 2500 acfm) of the flue gas from a 350-Mw, twin-furnace boiler firing 2.8- to 3.8-percent-sulfur coal. Dolomite was injected into one of the furnaces during a continuous thirty-day test, with the other furnace used as a control.

Combustion Engineering's first commercial-scale unit went on stream in October, 1968 at Union Electric's 140 Mw Meramec Station.[20] The plant has not yet attained its design capacity. Performance guarantees stated 83-percent removal of sulfur oxides and 99-percent removal of dust. Two other Combustion Engineering installations (one for a 125-Mw unit and the other for a 430-Mw unit) are in engineering and construction stages for Kansas Power and Light Company.[21] The smaller plant has started up.

5.2 FURNACE REACTIONS

Within the boiler furnace, a number of important reactions take place besides combustion of fuel and sulfur. These consist of calcination of the alkali solids, fixation of some of the sulfur oxides, and oxidation of some of these initial reaction products. A simplified version of these furnace reactions follows:

(1) $CaCO_3 \cdot MgCO_3(s) \rightarrow CaCO_3(s) + MgO(s) + CO_2(g)$

(2) $CaCO_3(s) \rightarrow CaO(s) + CO_2(g)$

(3) $CaO(s) + SO_2(g) + 1/2O_2(g) \rightarrow CaSO_4(s)$

(4) $CaO(s) + SO_2(g) \rightarrow CaSO_3(s)$

(5) $CaSO_3(s) + 1/2O_2(g) \rightarrow CaSO_4(s)$

(6) $MgO(s) + SO_2(g) + 1/2O_2(g) \rightarrow MgSO_4(s)$

(7) $MgO(s) + SO_2(g) \rightarrow MgSO_3(s)$

(8) $MgSO_3(s) + 1/2O_2(g) \rightarrow MgSO_4(s)$

Typical temperatures for calcining (Reactions 1 and 2) as performed in commercial lime burning are 1950-2100 F[22]. The sulfur oxides fixation (Reactions 3, 4, 6 and 7) have an optimum temperature range of 1600-1800 F[15]. The extent of the oxidation reactions (5, 8) and their optimum temperature have not been clearly defined in the literature.

The optimum temperature ranges for calcination and sulfite formation are similar. However, the boiler furnace design imposes some severe restrictions upon its use as a chemical reactor. If alkali solids injection is used without wet scrubbing, any sulfur fixation that occurs must depend upon the furnace reactions. The problem here concerns the short residence time of the reactants within the furnace and particularly the time within the critical temperature zone.

Estimates[15] state a residence time within the furnace of less than five seconds. Effective time within the critical temperature zone is not more than one or two seconds. In an effort to get as much residence time as possible, injection is made close to the burners, where a temperature of 3000 F exists. However, temperatures such as these do not produce calcine of high reactivity (high dissolution rate).[22] This becomes quite significant in the alkali scrubbing process.

5.3 CALCINATION

If alkali injection is to be followed by wet scrubbing, sulfur oxides fixation within the furnace becomes much less important. It now seems that the ability of lime to hydrate, or slake, rapidly in the scrubber solution may be a critical factor. This physical characteristic depends upon furnace conditions and on the properties of the limestone.

It is informative to review some of the technology of commercial lime production, since this effort is concerned with making a reactive, rapid slaking product. Consideration of a few aspects of lime-producing technology points out the limitations of the boiler furnace as a calciner. It also indicates that injection-port location may be important and it perhaps helps to explain some of the pH behavior of scrubber solutions.

High-calcium limestone decomposes into calcium oxide and carbon dioxide at 1650 F and 1.0 atmospheric pressure. Commercial lime burners calcine at somewhat higher temperatures (2100 F for high-calcium limestone and 1950 F for dolomite) to get better fuel efficiency and practical reaction rates. Higher burning temperatures and longer calcining periods result in a hard-burned lime of low chemical activity and slow slaking rate. Saleable limes demand burning temperatures not exceeding about 2200 F for high-calcium limestone.

Dolomitic limestones are calcined commercially about 200 F lower than high-calcium limestones. At this lower temperature, the magnesium oxide component is nearly always hard-burned. The resulting lime is less reactive and more difficult to hydrate than high-calcium lime.

Temperature of calcination affects the physical properties of lime much more than the calcination time period.[22] Tests show that increasing the temperature by 120 F is roughly equivalent to increasing the heating period from 2 to 10 hours. It has also been reported[22] that the rate of heating may have a greater influence on lime quality than any other calcining condition. Gradual rather than shock heating is recommended for the production of good reactive lime.[22]

Some important differences exist between a commercial lime kiln and a boiler furnace from the standpoint of a calciner. Limestone (0.25 to 2.5 inches in size) may be charged to a rotary kiln where it is gradually heated to 2100 F, cooled and discharged. Its total residence time may be 1/2 hour to 3 hours. In the boiler furnace, 200-mesh limestone is injected close to the burners where the temperature is about 3000 F. The temperature falls rapidly as gas and particles proceed through the furnace. The reactants probably reside in the effective calcination temperature range 1 or 2 seconds and reside less than 5 seconds within the entire furnace.

Little information has been published on the calcination of small limestone particles and their resulting characteristics. However, some interesting Russian work has been published on this subject.[23] Limestone particles in the 3-mm to 30-mesh range were calcined in a fluid-bed furnace. Calcination was accomplished as quickly as 0.05 seconds at temperatures not specified and was complete in 0.25 seconds at 2190 F. A considerable decrease in reactivity (measured by hydration period) was found when temperature was increased to 2550 F. Hydration periods were five minutes for 2190 F calcining and 16 minutes for 2550 F calcining.

The significance of lime hydration rate to the limestone scrubbing process is discussed later in subsection 5.3.2. Some conclusions that can be drawn from this discussion are summarized here.

- Injection of alkali solids near the fuel burner ports in the boiler furnace probably results in a hard-burned lime of poor reactivity and slow hydration rate. The problem is more acute when dolomitic limestones are used.
- Alkali injection ports should be investigated for a range of temperature zones (2300 F and lower). Arrangements should be made with TVA to do this phase of study at Shawnee Unit 10, Paducah, Kentucky.
- The small (200 mesh) limestone particles injected into the furnace, are probably completely calcined even though the residence time is less than 5 seconds.

- The temperature of calcining influences lime reactivity much more significantly than residence time. Commercial limes are usually not calcined above 2200 F.

- Rate of heating of the particles may have an important effect upon the reactivity of the lime. Shock heating, as occurs in the furnace, may have a negative effect on lime reactivity.

- Small-scale test data on calcination of small limestone particles is needed to determine the following:

    1. Residence time versus temperature for complete calcination
    2. Effect of calcination temperature on lime reactivity
    3. Effect of rate of calcining on lime reactivity
    4. Effect of particle size as a parameter in 1, 2, and 3 above

- The technique of injecting the limestone as a slurry should be considered because the method should provide good dispersion within the reaction zone and it could affect the temperature history of the particles. It may not be feasible to do this phase of study at the Detroit Edison plant.

5.4 CHEMISTRY OF SULFUR DIOXIDE ABSORPTION

5.4.1. Chemical Mechanism

The following reactions describe chemistry in the scrubber circuit. Although the equations are written for calcium-based alkali, similar ones apply for the magnesium oxide component of dolomite.

1. $SO_2 + H_2O \rightarrow H_2SO_3$
2. $CaO + H_2O \rightarrow Ca(OH)_2$
3. $Ca(OH)_2 + H_2SO_3 \rightarrow CaSO_3 + 2\ H_2O$
4. $CaSO_3 + H_2SO_3 \rightarrow Ca(HSO_3)_2$
5. $Ca(OH)_2 + Ca(HSO_3)_2 \rightarrow 2\ CaSO_3 + 2\ H_2O$
6. $CaSO_3 + 1/2\ O_2 \rightarrow CaSO_4$

Reaction 1 represents the first step of sulfur dioxide absorption to form sulfurous acid. Reaction 2 represents hydration, or slaking of lime. The time required for dissolution of lime is a critical factor in the process, as will be discussed later. Reaction 3 forms relatively insoluble calcium sulfite. Reaction 4 shows the conversion of calcium monosulfite to relatively soluble calcium bisulfite in the presence of excess sulfurous acid. Reaction 5 represents precipitation of the sulfur removed from the flue gas. Some of the sulfite oxidizes to sulfate, Reaction 6.

In the limestone scrubbing process, which circulates a solution saturated in calcium sulfite, the shift from monosulfite to bisulfite is considered to be the mechanism responsible for abosrbing sulfur dioxide from the gas. This is consistent with theory developed for producing cooking liquor in the pulp industry.[24]

It was previously stated that some calcium sulfite oxidized to sulfate in the furnace. Similarly, some oxidation will occur in the solution. The relative amounts of sulfate formed in the two locations are unknown. Both Combustion Engineering and Bahco have reported equal quantities of sulfate and sulfite in their process discharge. Regardless of the location of the oxidation reaction within the system, it appears that the circulating absorber solution is saturated with respect to both salts.

If the scrubber solution attains high alkalinity, calcium carbonate will precipitate, resulting in loss of alkali. The solubility of carbon dioxide in the solution is much less than sulfur dioxide, but can be solubilized to some extent by formation of calcium bicarbonate.

7. $2CO_2 + Ca(OH)_2 \longrightarrow Ca(HCO_3)_2$

However, at higher solution pH's, Reaction 8 occurs.

8. $Ca(HCO_3)_2 + Ca(OH)_2 \longrightarrow 2CaCO_3 + 2H_2O$

5.4.2 Alkali Hydration

The rate at which lime can be put into solution appears to be a critical factor in the limestone scrubbing process. Published data[22, 23, 25] show that the time required to dissolve lime varies from seconds to days. Calcination of the limestone is perhaps the most important factor influencing the dissolving rate and this subject has already been discussed. It should be restated, however, that dolomitic limestones usually result in some hard-burning of the magnesium oxide, which leads to much slower hydration rates.

The reaction within the furnace that reacts solid calcium oxide with sulfur dioxide could also affect slaking. Some of the calcium oxide that is not completely converted to calcium sulfite or sulfate may be predominantly oxide covered with a shell of sulfite or sulfate. Particles such as these may be difficult to dissolve, particularly in a solution saturated with sulfite and sulfate. This condition could be improved by agitation within the liquid phase.

Some of the other more important factors that influence hydration rate are as follows:

- The velocity of hydration approximately doubles for each 10 C rise in temperature. Commercial hydration is usually done between 180 F - 190 F.
- Doubling the surface area doubles the rate of solution.
- If lime reacts with an excess of acid to form an insoluble salt, the rate of solution is retarded since the resulting salt encrusts the lime particles.
- If lime reacts with an excess of acid to form a soluble salt, the rate of solution increases.

On the basis of the literature, it appears that slaking times for limes normally range from 5 to 30 minutes.

The major equipment components of the scrubber solution circuit consist of the scrubber, the scrubber effluent hold-tank, the clarifier, and the process water hold-tank. For a typical system operating rate of 100,000 acfm of gas and 2000 gpm of liquid, the residence times would be as follows:

Component	Residence Time
TCA Scrubber	6-10 seconds
Clarifier	2 hours
Hold-up Tanks	4 minutes each

These estimates indicate that the scrubber alone cannot provide enough residence time for dissolution but must be supplemented in this regard by the clarifier and hold-tanks.

There is the possibility that solid calcium oxide particles entering the clarifier may settle to the bottom rather quickly and leave before dissolving. The clarifier operation would then have to be modified to slow the settling and allow adequate time for dissolution. This would result in some suspended solids in the overflow that is recirculated to the scrubber.

If an attempt is made to bypass the clarifier and all tanks, there does not appear to be adequate residence time for alkali dissolution. Even if a particle recirculates through the scrubber ten times before leaving the system, its total residence time will be only about a minute.

If the clarifier is bypassed and one or both hold-tanks are used, there may be enough time to dissolve the alkali. This will have to be determined by facility operation or by some auxilliary small-scale testing.

Boynton[22] has stated that calcium sulfate inhibits the solubility of calcium hydroxide. The solubility was given as 0.0062 grams per 100 grams solution at 25 C in a 0.2-percent calcium sulfate solution. Solubility of calcium hydroxide in water is 0.16 grams per 100 grams of solution. If true, this is a startling phenomenon. However, this data should be confirmed by further literature search or by laboratory test.

5.4.3 Supersaturation

The Howden-I.C.I. cyclic lime process,[2] mentioned previously, used both lime and chalk ($CaCO_3$) as alkali. The circulating absorbing liquor contained 10 to 15 percent solids in suspension ($CaSO_3 \cdot 2\,H_2O$, $CaSO_4 \cdot 2\,H_2O$, CaO, $CaCO_3$). By careful control, no solids crystallized onto the absorber surfaces.

The technique was based upon the property of calcium sulfate and sulfite salts to form fairly stable supersaturated solutions. Liquor entering the top of the absorber was saturated with sulfite and sulfate. During its passage through the absorber, the liquor became slightly supersaturated from the newly formed sulfite and sulfate. The liquor system outside the scrubber had hold tanks to provide the time-delay required to destroy the supersaturation. The solids make was removed and saturated liquor recirculated.

R. Lessing[2] produced curves showing rate of de-supersaturation of calcium sulfate solutions with various concentrations of suspended gypsum. The English work stated that, in the fully developed process, the supersaturation scheme only applied to calcium sulfate because of the increased solubility of calcium sulfite with the diminishing pH of liquor passing through the scrubber.

5.4.4 Composition of Solution During Operating Cycle

The significance of the process chemistry can be shown by following the solution through an absorption cycle. Reaction 4 showed that the sulfite to bisulfite shift ($CaSO_3 + H_2SO_3 \longrightarrow Ca(HSO_3)_2$) is responsible for absorption of SO_2. This means that the solution entering the top of the scrubber need not contain calcium hydroxide if there is the required stoichiometric amount of calcium sulfite present.

Both the Howden-I. C. I. and Bahco processes report pH's between 6 and 7 for liquor entering the absorber. This would indicate a sulfite solution rather than one of appreciable calcium hydroxide concentration.

If a saturated sulfite solution with no suspended solids is to be used, the solubility of calcium sulfite determines the circulation rate. If low solubility makes the circulation rate too large, the problem can be overcome. Calculations show that a suspended solids content of less than 0.5 percent will supply the calcium sulfite requirement with a very reduced stream size. Solubility data on the $CaSO_3$-$Ca(HSO_3)_2$-$CaSO_4$-H_2O system is needed.

As the liquor passes down through the scrubber, it absorbs sulfur dioxide, sulfite shifts to bisulfite, and the pH falls to between 5 and 6. Entering gas brings with it the alkali solids but these do not have time to dissolve within the scrubber. In the solution circuit outside the scrubber (clarifier, hold-tanks), residence time is provided for the alkali to dissolve to form calcium hydroxide. The soluble alkali then reacts with the bisulfite to precipitate $CaSO_3 \cdot 2H_2O$ as in Reaction 5 ($Ca(OH)_2 + Ca(HSO_3)_2 \longrightarrow 2CaCO_3 + 2H_2O$).

Thus, the sulfur that entered the system with the flue gas was first physically absorbed in water, then formed soluble calcium bisulfite, and was finally precipitated as calcium sulfite. The sulfur leaves the system as calcium sulfite or sulfate. In actual system operation, the solution entering the scrubber may have to contain some excess calcium sulfite or calcium hydroxide. This is because the equilibrium vapor pressure of sulfur dioxide over the solution increases with bisulfite concentration, thus decreasing the driving force for absorption.

The chemistry has been discussed on the basis of high-calcium limestone and lime. The same equations apply to the magnesium oxide content of dolomitic limes; however, some significant differences in system operation would occur due to differences in the solubilities of magnesium hydroxide and magnesium sulfite. The different hydration rate of magnesium oxide may be important. As a result of solubility differences, the vapor-liquid equilibrium for sulfur dioxide will change.

The quantitative changes in process operation due to changing from high-calcium lime to dolomite cannot be predicted. However, some general trends are indicated. Calcium hydroxide is about 100 times more soluble than magnesium hydroxide, and its slaking rate is considerably faster. Magnesium sulfite is much more soluble than calcium sulfite, which results in a smaller solution circulation.

The effect of temperature on the system is complex. Sulfur dioxide absorption favors lower temperatures: some sulfite pulp industries resort to refrigeration to cool the solution to 70 F or lower. The rate of lime dissolution increases with temperature and is done commercially at 180 F. The solubility of calcium hydroxide increases significantly with decreasing temperature. The effect of temperature on sulfite solubility does not appear to be very significant.

5.4.5 Ionic Equilibrium

If the ionic equilibrium, which governs solution composition, could be quantitatively represented, it would be valuable for process design and operation. Kesler and Han[26] have proposed a model and mathematical solution for the magnesium-base sulfite cooking liquor. Their calculations are based on dissociation and solubility data. Although the limestone-scrubbing test facility is more complicated because of the presence of sulfate, the Kesler and Han method could be extended to cover it.

The following equilibria fix the composition of the liquid phase:

1. $SO_2 + H_2O \rightleftharpoons H_2SO_3$

2. $H_2SO_3 \rightleftharpoons H^+ + HSO^-_3$

   $HSO^-_3 \rightleftharpoons H^+ + SO^=_3$

3. $CaSO_{3(s)} \rightleftharpoons Ca^{++} + SO^=_3$

4. $CaSO_{4(s)} \rightleftharpoons Ca^{++} + SO^=_4$

5. $Ca(OH)_{2(s)} \rightleftharpoons Ca^{++} + 2OH^-$

6. $Ca(HSO_3)_2 \rightleftharpoons Ca^{++} + 2HSO^-_3$

   $HSO^-_3 \rightleftharpoons H^+ + SO^=_3$

7. $H_2O \rightleftharpoons H^+ + OH^-$

Calcium is distributed as follows:

8. $Ca = Ca^{++} + CaSO_{3(s)} + CaSO_{4(s)} + Ca(OH)_s$

Sulfur dioxide is distributed as follows:

9. $SO_2 = CaSO_{3(s)} + CaSO_{4(s)} + H_2SO_3 + HSO^-_3 + SO^=_3$

A tenth equation can be established by an ionic-charge balance.

For a constant total sulfur dioxide content, Equation 1 can be eliminated from the calculations. This results in nine simultaneous equations that can be solved by computer. Thus, it is possible to calculate the species present at any solution pH and to predict pH values at which solid phase calcium sulfite, calcium sulfate, and calcium hydroxide will precipitate.

The most serious problem involving the application of these equations to limestone scrubbing concerns the true solubility data for calcium sulfite in a solution of calcium bisulfite and calcium sulfate.

5.4.6 Gas-Liquid Phase Equilibrium

In the alkali scrubbing process phase, equilibria establish the limits of process performance. In order to determine the maximum sulfur dioxide removal efficiency possible, the equilibrium sulfur dioxide concentration in the gas contacted by the alkali scrubbing solutions must be known.

The equilibrium between sulfur dioxide gas and aqueous solutions based on calcium and magnesium have been investigated by a number of workers. Unfortunately, most of the data presented are for conditions other than those encountered in the alkali scrubbing of combustion flue gas. However, some of these data can be used to estimate the equilibrium conditions for the process. Only a limited amount of data for aqueous solutions based on both calcium and magnesium (dolomite systems) was found.

Calcium Oxide System. The vapor pressure of sulfur dioxide (P_{SO_2}) over aqueous solutions of calcium bisulfite and calcium sulfite has been investigated by a number of workers [27, 28, 29, 30, 31, 32, 33] from the standpoint of use in sulfite-pulping. However, only the data of Conrad and Beuschlein[28] and Kuzminykh and Babushkina[33] are for solutions saturated with calcium sulfite, a condition which would probably be encountered in the solutions used for flue gas scrubbing. Use of their data for evaluating P_{SO_2} values is, however, limited by the range of P_{SO_2} values measured. This is because in neither case was calcium sulfate present in the solutions investigated. The lack of calcium sulfate in the solutions limits the value of their results, because it will be present in significant concentrations in flue gas scrubbing solutions. Its presence, as will be shown in the case of magnesium solutions, could have a significant effect on P_{SO_2} values.

Of the available data for calcium-sulfite-saturated solutions, those of Kuzminykh and Babushkina are the most accurate and cover lower P_{SO_2} values. Their measurements are for a P_{SO_2} range of 20 to 300 mm of Hg for five temperatures (4.5, 15, 25, 50, and 60 C). Since the P_{SO_2} for combustion flue gas is on the order of 1 mm of Hg, these data are for a higher range than will be encountered in flue gas scrubbing. These values do, however, indicate that the sulfur dioxide equilibrium relation for this system is not linear for P_{SO_2} values of interest in alkali scrubbing; i.e., Henry's law may not apply. The values also show that, as the temperature increases, the P_{SO_2} increases for a given solution composition. At 25 C the P_{SO_2} for a calcium-sulfite-saturated solution with a total sulfur dioxide concentration of 3.64 g per 110 g of H_2O is 31 mm of Hg. For the same solution at 50 C, the P_{SO_2} is 73.4 mm of Hg.

Kuzminykh and Babushkina also established that the transition point between solid $CaSO_3 \cdot 2H_2O$ and $CaSO_3 \cdot 0.5H_2O$ is 37 C. Above this temperature, $CaSO_3 \cdot 0.5H_2O$ will precipitate from saturated solutions and below it $CaSO_3 \cdot 2H_2O$ will precipitate.

Magnesium Oxide System. Like the calcium system, the magnesium system has been investigated by a number of workers[27, 34, 35, 24, 36] because of its importance in pulping. Fortunately, unlike the calcium system, some of the available data are for P_{SO_2} values in the range and under conditions encountered in alkali scrubbing.

Pinaev[36] has measured the P_{SO_2} over aqueous magnesium bisulfite solutions saturated with magnesium sulfite and containing various quantities of magnesium sulfate over the range 0.03 to 0.15 mm of Hg at four temperatures 30 C, 40 C, 50 C, and 60 C. His results are shown in Table 5-2 for 40 C, a temperature within the 35 to 50 C operating range of the alkali scrubbing process.

The values in the "Total SO_2" column represent the amount of sulfur dioxide in the solution due to magnesium bisulfite and magnesium sulfite. The amount of sulfur dioxide present as magnesium sulfate is not included in the "Total SO_2" values because it does not take a direct part in the absorption of sulfur dioxide. Magnesium sulfate concentrations are shown in column 3.

Pinaev's data supports the conclusion, made from the calcium bisulfite solution equilibrium data, that the equilibrium curve is non-linear in the region of interest. The equilibrium function calculated by Pinaev from his data is

$$\log P_{SO_2} = b\,(\log C_{SO_2}) - a$$

where C_{SO_2} is the "Total SO_2" concentration in solution and "a" and "b" are constants that depend upon solution temperature and the concentration of magnesium sulfate in the solution.

Table 5-1

EQUILIBRIUM SO_2 VAPOR PRESSURE AT 40 C FOR MAGNESIUM BISULFITE SOLUTIONS SATURATED WITH SULFITE AND CONTAINING SULFATE

P_{SO_2} (mm of Hg)	Total SO_2 (g/liter)	$MgSO_4$ Concentration (g/liter)	SO_2/Mg Ratio (mole/mole)	pH at 30 C
0.038	8.20	51.20	1.28	5.82
0.048	11.84	51.85	1.47	5.70
0.065	18.5	52.63	1.60	5.29
0.089	25.9	51.13	1.65	5.10
0.042	10.5		1.19	5.09
0.051	14.1	81.32	1.35	5.04
0.079	20.2	81.10	1.50	4.87
0.167	28.3	79.00	1.65	4.64
0.050	8.95	101.26	1.25	5.20
0.102	18.8	105.50	1.54	4.90
0.130	24.5	106.89	1.70	4.60
0.048	10.0	119.20	1.21	4.80
0.058	11.5	126.30	1.43	4.65
0.110	20.0	120.83	1.51	4.40
	25.2			

The effect of magnesium sulfate upon P_{SO_2} is apparent from Table 5-1 for concentrations up to 120 grams per liter. As the magnesium sulfate concentration increases, the P_{SO_2} increases for a given "Total SO_2" value. For a "Total SO_2" of approximately 20 grams per liter, P_{SO_2} increases from approximately 0.070 mm Hg at 50 grams per liter of magnesium sulfate to approximately 0.105 mm Hg at 100 grams per liter magnesium sulfate. Solubility data[37] for magnesium sulfate in magnesium sulfite solutions indicates that the magnesium sulfate concentration could get appreciably above 120 grams per liter. The saturation level for magnesium sulfate in magnesium sulfite solutions at 40 C is reported[37] to be on the order of 375 grams per liter.

Table 5-1 also indicates the relationship between P_{SO_2} and the molar ratio of the sulfur dioxide and magnesium present in solution as magnesium bisulfide and magnesium sulfite. This ratio can be used as a measure of a solution's ability to absorb sulfur dioxide since it indicates the degree of saturation of the solution with regard to magnesium bisulfite and, consequently, the P_{SO_2} over the solution. The ratio is 1 in the absence of magnesium bisulfite and 2 in the absence of magnesium sulfite. Since the P_{SO_2} is practically equal to zero over pure magnesium sulfite solutions and, in terms of flue gas scrubbing, high over high magnesium bisulfite solutions, a solution for use in SO_2 absorption should be close to 1. Pinaev's data indicates that, in the case of magnesium bisulfite solutions saturated with magnesium sulfite and containing less than 120 grams per liter of magnesium sulfate, the maximum value of the SO_2/Mg ratio for sulfur-dioxide removal efficiencies on the order of 90 percent is 1.5 to 1.6.

Besides the P_{SO_2} data of Pinaev, those of Markant, McIlroy, and Matty[24] are of interest. Though only a few points are presented at P_{SO_2} values below 1 mm of Hg and no magnesium sulfate is present, they support the values reported by Pinaev.

5.5 CONCLUSIONS AND RECOMMENDATIONS

The conclusions and recommendations listed below are ones that seem particularly relevant to the initial planning and process-design aspects of the limestone scrubbing project.

1. The alkali additive must be calcined carefully under optimum conditions to result in efficient scrubber operation. The injection port locations at the Detroit Edison plant may or may not be favorable for producing a lime that has a dissolution rate that corresponds to the solution residence time. Study of port locations should be made at a facility such as the TVA's Shawnee Unit. The particular range of interest is 2300 F and slightly lower. Slurry injection should also be considered to decide if it is worthwhile pursuing in a test program.
2. Calcination tests on small limestone particles are needed to develop data on the effects of temperature, time, and rate of heating on lime reactivity. The effect of particle size and magnesium oxide content should also be determined. (The term reactivity as it is used here refers particularly to lime hydration-times.)
3. In the limestone scrubbing process, the shift from calcium sulfite to bisulfite is considered to be the mechanism responsible for absorption of sulfur dioxide from the flue gas.
4. The efficiency of the scrubber system depends on careful control of the circulating solution composition. Solubility of calcium sulfite in aqueous solutions of calcium bisulfide and calcium sulfate is here a critical factor. Tests are needed to develop solubility data for this system.
5. Residence time for the circulating solution within the circuit is critical. The correct residence time permits lime to hydrate rather than to be discharged unreacted. Proper timing also may have an important influence on the scaling of solids onto surfaces. Since optimum residence time cannot be accurately predicted, the test facility should provide some flexibility. This can be done by holding tanks and bypasses.
6. Temperature has a definite effect on sulfur dioxide absorption. Sulfur dioxide absorption and calcium hydroxide solubility favor lower temperatures while rate of dissolution of calcium oxide increases with temperature. Sulfite solubility is not greatly affected by temperature. Some

consideration should be given to the possibility of designing temperature-control flexibility into the scrubbing system.

7. Sufficient gas-liquid phase equilibrium data are not available for the gas-phase sulfur dioxide concentrations of interest for both the limestone and dolomite cases. These data need to be developed in order to evaluate scrubber performance in the test facility and for the design of full-scale systems. In developing it, specific attention should be given to the effects of sulfite and sulfate concentrations upon the equilibrium curve.

8. The indicated effect of calcium and magnesium sulfate upon the gas-liquid phase equilibrium in the corresponding bisulfite-sulfite solutions is to increase the sulfur dioxide vapor pressure at a given bisulfite-sulfite ion concentration. This is one reason why the effect of sulfate concentration upon equilibrium needs to be carefully evaluated.

Table 5-2

PROCESS REVIEW

Process Step	Data Needed	Reason for Needing Data	Intended Use of Data
Pulverization	Optimum particle size distribution	To determine optimum particle size for rapid calcination dissolution	To specify pulverize and operation
Injection	Optimum injection location and temperature in furnace	To determine desired calcination and gas-solid reaction effect on dissolution	To specify number, sign, and location of jection ports
Calcination	Extent of calcination vs. temperature and residence time, particle-surface condition	To determine optimum dissolution rate	To determine particl size and temperature calcination and rapid dissolution
Gas-Solid Reaction	Extent of reaction of SO_2 and SO_3 with CaO vs. temperature, particle size, particle-surface condition, and extent of oxidation of $CaSO_3$ to $CaSO_4$ vs. O_2 content of flue gas. Extent of shell formation of $CaSO_4$ on CaO particles	To determine effect of scrubber inlet-gas composition on SO_2 recovery and effect of $CaSO_4$ shell on CaO solubility	To help specify parti size, port location, product solution rate to establish gas comp sition for scrubber d sign, and to design fo resulting CaO solubil
Oxidation of $CaSO_3$ to $CaSO_4$ in Furnace	Rate of oxidation in furnace, influence of Fe, effect of T, particle surface, particle size, composition of gas	To determine means of influencing solubility of SO_2 and reducing CaO dissolution in scrubbing solution	To calculate material balance and set liquo composition

A

Table 5-2

PROCESS REVIEW

	Intended Use of Data	Data Now Possessed	What Test Program Will Determine
	To specify pulverizer and operation	Pulverization requirements for optimizing reaction between gaseous SO_2 and solid lime. This refers to alkali injection-dry process, German, Japanese, U. S. data	Pulverization conditions for optimizing disolution rate of lime in scrubber solution
l- eac- h	To specify number, design, and location of injection ports	Alkali injection port locations for optimizing reaction between gaseous SO_2 and solid lime. This refers to alkali injection-dry process, German, Japanese, U. S. data	Injection port locations for optimizing dissolution rate of lime in scrubber solution
	To determine particle size and temperature for calcination and rapid dissolution	Calcination conditions vs. lime dissolution rate for narrow range of calcining conditions	This is outside the scope of the test facility.
y l	To help specify particle size, port location, and product solution rate; to establish gas composition for scrubber design, and to design for resulting CaO solubility	Considerable data from alkali injection-dry process (German, Japanese, U. S.) on sorption of SO_2 by lime. This data gives some consideration to oxidation of $CaSO_3$ to $CaSO_4$; brief consideration of $CaSO_4$ shell formation.	Effects of oxidation and shell formation on scrubber performance and system operating requirements to minimize these effects
	To calculate material balance and set liquor composition	Mostly data on the effect of oxidation on sorption of SO_2 in alkali injection-dry process. Literature statements that $CaSO_4$ affects solubility of SO_2 and CaO in aqueous solutions	Chemical composition of particles entering scrubber and correlation with maximum particle temperature, iron content of limestone, particle size, and gas composition

B

Table 5-2 (Cont)

PROCESS REVIEW

Process Step	Data Needed	Reason for Needing Data	Intended Use of Data
Oxidation of $CaSO_3$ to $CaSO_4$ in Solution	Rate of $CaSO_3$-to-$CaSO_4$ conversion in scrubber and conditions that will minimize this conversion in scrubber	To determine means of reducing chemical oxygen demand of clarified solids, as to minimize plugging and to determine the effect of $CaSO_3$ on SO_2 and $Ca(OH)_2$ solubility	To control pollution to aid making mater balance calculation establishing liquor position
Solubilities	Solubility of $Ca(OH)_2$ in $CaSO_3$ and $Ca(HSO_3)_2$ solutions saturated with $CaSO_4$	To determine solution equilibria and to make crystallization, plugging, and process calculations	To calculate materi balance and to desig scrubber and dissol tank
Solution Reactions	Ionic equilibrium and reaction kinetics for: 1. $SO_2 + H_2O \rightleftharpoons H_2SO_3$ 2. $H_2SO_3 \rightleftharpoons H^+ + HSO_3^-$ $HSO_3^- \rightleftharpoons S^+ + SO_3^=$ 3. $CaSO_{3(s)} \rightleftharpoons Ca^{++} + SO_3^=$ 4. $CaSO_{4(s)} \rightleftharpoons Ca + SO_4$ 5. $Ca(OH)_2 \rightleftharpoons Ca^{++} + 2OH^-$ 6. $Ca(HSO_3)_2 \rightleftharpoons CA^{++} + 2HSO_3^-$ $HSO_3^- \rightleftharpoons H^+ + SO_3^=$ 7. $H_2O \rightleftharpoons H^+ + OH^-$	To determine liquid circulation rates and composition for high SO_2 removal	To calculate materi balance and design scrubber and to esta lish a process desig model
Clarification of Scrubbing Liquor	Feed composition as % suspended solids, particle size, specific gravity, % solids in overflow and underflow	To determine design conditions for clarifiers	To specify clarifier

A

e 5-2 (Cont)

CESS REVIEW

	Intended Use of Data	Data Now Possessed	What Test Program Will Determine
- e- as to SO_3 ility	To control pollution and to aid making material balance calculations and establishing liquor composition	None	Chemical analysis of scrubber solution
i- - o-	To calculate material balance and to design scrubber and dissolution tank	Enough data to indicate important effects, but not enough data for design	This is outside the scope of the test facility.
al	To calculate material balance and design of scrubber and to establish a process design model	Description for model for a similar but simpler Mg system	The lab work is outside the scope of the test facility but a mathematical model can be developed
	To specify clarifier	None	Settling characteristics of scrubbing liquor

B

Table 5-2 (Cont)

PROCESS REVIEW

Process Step	Data Needed	Reason for Needing Data	Intended Us of Data
Filtration	Cake resistance, density, and % moisture in cake	To establish design conditions for filter	To specify filte
Solution Pumping	Specific gravity, viscosity, and % solids of slurry	To determine pressure drop and effect of slurry on pumping requirement and scrubber operation	To specify pum determine line scrubber desig
Reheating	Minimum temperature of plume formation vs. atmospheric conditions, effect of entrainment on reheating temperature, effect on plugging of ID fan	To minimize reheating and prevent plugging of ID fan	To specify ID fa reheater

A

Table 5-2 (Cont)

PROCESS REVIEW

	Intended Use of Data	Data Now Possessed	What Test Program Will Determine
-	To specify filter	None	Run small-scale filtration leaf tests
drop nd	To specify pumps and determine line size and scrubber design	None	Measure specific gravity, viscosity, and % solids of slurry at test facility
and fan	To specify ID fan and reheater	Reports of Meramec facility performance	Performance of three reheater systems

B

Section 6

SCRUBBER EVALUATION

A number of scrubber designs exist for removing sulfur oxides and particulates from flue gas. The problem is one of selecting those with performance characteristics that match the requirements of the alkali solids injection-wet scrubbing process. To accomplish this, various designs were evaluated in terms of their effectiveness as SO_2 absorbers and particulate collectors under the operating conditions expected for the process. This led to elimination and selection decisions based on fundamental scrubber design features.

Performance and design information was obtained from the published results of research on alkali solids injection-wet scrubbing and related processes, from meetings with scrubber manufacturers, and from observation of scrubbers operating under conditions similar to those anticipated for the test facility. Table 6-1 lists manufacturers contacted and the scrubber designs that they offered. Design of the flooded-bed scrubbers installed by Combustion Engineering, Inc., at Union Electric Company's Meramec Plant was investigated in detail. Meetings with Dominion Tar and Chemical Company, Ltd., provided an opportunity to observe operation of large-size, turbulent-contact and venturi scrubbers. A visit to the City of Pasadena's municipal power plant in California allowed observation of the operation of a large impingement-plate scrubber for the removal of ash from flue gas during the cleaning of an oil-fired steam generator. The information used to evaluate scrubber design is summarized in Table 6-5 at the end of this section. Also

Table 6-1

SCRUBBER MANUFACTURERS CONTACTED AND TYPES OF SCRUBBERS OFFERED

Universal Oil Products, Air Correction Division	Turbulent Contact, Venturi
National Dust Collector Corporation	Flooded Bed
Peabody Engineering Corporation	Impingement Plate
Research-Cottrell, Inc.	Flooded-Disc Venturi
Chemical Construction Corporation	Venturi
W. W. Sly Manufacturing Company	Impingement Plate
Western Precipitation Group, Joy Manufacturing Company	Venturi, Submerged Nozzle
Taylor and Company, Inc.	Combination
Babcock and Wilcox Company	Venturi
Ceilcote Company, Inc.	Cross Flow, Wet Cyclone, Venturi
Arco Industries, Inc.	Impingement Plate, Wet Cyclone, Venturi
Fly Ash Arrestor Corporation	Combination, Venturi

indicated in this table is scrubber performance information that will be determined in the test program. Abbreviations used are listed at the end of the table. The OR between the first column of Items 1 and 2 means that two methods could be used: direct comparison of scrubber SO_2 removal efficiencies or calculation of efficiencies from equilibrium and mass transfer data.

6.1 SULFUR DIOXIDE ABSORPTION

Removal of SO_2 from flue gas by sulfite solutions is a mass-transfer operation involving both absorption and chemical reaction. Several idealized mathematical models have been developed for absorption without chemical reaction. Of these, the most frequently used are the two-film theory[38] generally credited to Whitman and the penetration theory of Higbie.[39] Recently, various surface-renewal models[40] derived from penetration-theory concepts have also been used.

These theories all maintain that, when a gas mixture containing a component soluble in a specific solution is brought in contact with that solution, interphase mass transfer will occur unless the two phases are in equilibrium with regard to the component. In formulating equations that relate the rate of transfer to gas and solution properties, the assumption is made that equilibrium exists at the gas-liquid interface immediately after the phases come into contact. Further, if absorption occurs, the component concentration or component partial pressure, p_i, in the gas phase at the interface must be less than in the bulk of the gas. Thus, if p_o is the average partial pressure of the component in the gas, the difference $p_o - p_i$ provides a driving force for transport of the component to the phase interface. A similar situation is postulated for the liquid phase; i.e., the difference between the component concentration at the interface c_i and the average concentration c_o in the liquid, $(c_i - c_o)$, provides a driving force for transport of the component from the interface into the liquid.

Since equilibrium is assumed at the interface, the rate of transfer out of the gas phase is equal to the rate of transfer into the liquid phase. These rates are stated to be proportional to the driving forces. Thus, if N_a is the rate of transfer of component A,

$$(1) \quad N_a = k_g \, (p_{oa} - p_{ia}) = k_l \, (c_{ia} - c_{oa})$$

where k_g is the gas-phase mass-transfer coefficient and k_l the liquid-phase mass-transfer coefficient.

Equation (1) applies to the case of absorption in which the transferring component does not react with material in the liquid phase. However, if such a reaction does occur, as in the case of SO_2 absorption by bisulfite-sulfite solutions, the equation can be modified to account for the effect of the reaction by expressing the liquid mass transfer coefficient in the form:

$$k_l^* = k_l \phi$$

Here, ϕ represents the effect of chemical reaction on k_l, the liquid phase coefficient without chemical reaction. The value of ϕ depends upon the kinetics of the chemical reaction, the concentration and diffusivities of the reactants and products, and the absorption model used. For the case in which component A dissolves in the liquid phase and reacts irreversibly with a nonvolatile component, Brian,[41] using the penetration theory, developed a general model that calculates the value of ϕ. However, sufficient data for application of this model to the process and equipment being considered here have not been developed. Also, considering the scale of the test facility and the conditions under which it will operate, it is not feasible to collect the data required for substantiation and subsequent use of such a model.

A more reasonable approach to the problem of evaluating scrubbers on the basis of SO_2 absorption capability is through the use of overall mass transfer coefficients. Since it is impossible to determine the values p_i and c_i in equation (1), it is usual to define a new driving force based on c_e, the liquid equilibrium concentration corresponding to the average partial-pressure of component A in the gas phase, p_o, and on p_e, the gas-phase-equilibrium partial pressure corresponding to the average concentration of A in the liquid phase. The equation relating to the rate of mass transfer and the driving forces for transfer then becomes:

$$(2) \quad N_a = K_g (p_{oa} - p_{ea}) = K_l (c_{ea} - c_{oa})$$

Here, K_g is the defined as the overall gas-phase mass-transfer coefficient and K_l the overall liquid-phase mass-transfer coefficient. The overall coefficients differ from those in equation (1) in that they account for the entire transport resistance present in both phases, rather than in a single phase. These coefficients, however, have a disadvantage in that, unlike those defined in equation (1), they are dependent upon the concentration of component A in the gas and liquid phases for systems in which the equilibrium curve is not linear. As discussed in Section 5, it has not been possible from available data to determine the shape of the equilibrium curve for SO_2 over bisulfite-sulfite solutions in the concentration range of interest. If the equilibrium curve for this system is not close to being linear, the K coefficients determined by use of equation (2) will apply only to the SO_2 concentration ranges from which they were calculated. This may not be a severe restriction, since the SO_2 concentrations in both the gas and liquid phases to be investigated in the test facility will be in the same concentration range as would be encountered in commercial use of the process.

For SO_2 bisulfite-sulfite absorption, the solution SO_2-concentrations can be taken as the sum of the SO_2 present as free dissolved SO_2 and that combined in HSO_3^-, and $SO_3^=$ ions. Therefore, for the case of interest, equation (2) becomes,

$$(3)\quad N_A' = K_G\,(P_{oso_2} - P_{eso_2}) = K_L\,(C_{eso_2} - C_{oso_2})$$

where C_{eso_2} is the total SO_2 present in a solution in equilibrium with a gas having an SO_2 partial pressure equal to P_{so_2}, and P_{eso_2} is the partial pressure of SO_2 in the gas phse in equilibrium with a solution having a total SO_2 concentration of C_{oso_2}.

For this system, measurement of C_{oso_2} is considerably more difficult than for P_{oso_2}. Also, P_{oso_2} can be easily measured continuously, while C_{oso_2} would probably have to be measured intermittently by chemical analysis. Therefore, it is recommended that in general the gas-phase overall coefficient be used to evaluate and compare scrubber performances in the test facility.

Equation (3) applies to only one position in the scrubber. However, it can be combined with the absorber material-balance to yield an equation that relates the rate of mass transfer to the absorber inlet and outlet gas-phase SO_2 concentrations. The derivation of this equation is as follows:

If Z = the scrubber height (in feet) over which the gas and liquid solution are in contact,

G = the total gas flow rate (in lb-moles/hr-ft^2 of scrubber cross-section area) through the scrubber,

y = the flue gas SO_2 concentration (in mole-fraction),

y_e = the SO_2 concentration in the flue gas that would be equilibrium with the liquid phase (in mole-fraction),

K_g = the overall gas-phase mass-transfer coefficient (in lb-moles/hr-ft^2 - mole-fraction), A = the interfacial dry surface per unit volume of space in which the gas and solution are in contact (ft^2/ft^3), and

P_t = total pressure (in atm.), it can be shown[42, 43] for SO_2 present in the gas in dilute concentration that equation (3) leads to

$$(4) \quad G\,dy = K_G a P_t (y - y_e)\, dZ$$

The term "a" in this equation accounts for the difference between the liquid surface actually exposed to the gas phase and the physical surface presented by the scrubber. Since both a and K_G depend on the way in which the surface for transfer is generated, they are usually combined and treated as a single value, $K_G a$.

Equation (4) can be rearranged and integrated with regard to Z to yield Z in terms of a component (known as the height per transfer unit, H_{tOG} or H. T. U.) that is dependent upon G and $K_G a$ and a component dependent on y and y_e (known as the number of transfer units, N_{tOG}). Thus,

$$(5) \quad \int_{Z_2}^{Z_1} dZ = \frac{G}{K_G a\, P_t} \int_{y_2}^{y_1} \frac{dy}{y - y_e}$$

$$(6) \quad Z = H_{tOG} N_{tOG}$$

where

$$(7) \quad N_{tOG} = \int_{y_2}^{y_1} \frac{dy}{y - y_e}$$

and y_1 is the SO_2 concentration in the incoming flue gas and y_2 in the exiting gas.

The height Z will be defined specifically for each scrubber design. For instance, for scrubbers employing packing or mobile beds, Z could be the height of the packing or the height of the static bed.[44]

Equation (7) can be evaluated in two ways; by graphical integration if the operating line is curved and by direct integration if it is linear. For the case of a linear operating line and linear equilibrium curve, the integration yields[42, 43]

$$(8)\quad N_{tOG} = \frac{y_1 - y_2}{(y - y_e)\ m}$$

where $(y - y_e)m$ is the logarithmic average of the concentration differences at the entrance and exit of the scrubber and is equal to,

$$(9)\quad (y - y_3)m = \frac{(y - y_e)_1 - (y - y_e)_2}{\ln \dfrac{(y - y_e)_1}{(y - y_e)_2}}$$

For the test facility scrubbers, equation (8) may give satisfactory results provided the flue gas entering the scrubbers is saturated with water vapor, and little or no CO_2 is transferred to the scrubbing solution.

The mass transfer model described by Equations (4) through (9) is not the only model that could be developed. However, at the present time it is believed to be a reasonable compromise between what is known and not known about the process. As a result of operating the test facility, it is expected that a more specific model will be possible. References 42 and 43 develop other models that may be applicable to the SO_2 system of interest.

The overall mass transfer coefficient and H_{tOG} are dependent upon scrubber operating conditions and the properties of the gas and liquid phases. The effect of these conditions and properties can be correlated most effectively with K_Ga or H_{tOG} by use of dimensionless groups and specific variables.

Important dimensionless groups are the Schmidt number defined as

$$Sc = \frac{\mu}{\rho D}$$

and the Reynolds number defined as

$$Re = \frac{d\,G_m}{\mu}$$

where μ = viscosity

ρ = density

D = diffusivity of SO_2

d = a characteristic scrubber dimension

G_m = mass velocity

Important specific independent variables are the gas and liquid flowrates, sulfite and total SO_2 concentration of the scrubbing solution, temperature, and flue-gas SO_2 concentration.

Several workers,[44, 45, 46] have developed correlations for SO_2 scrubbing of the type described. Johnstone and Silcox[44] in their investigation of cyclone spray towers found the mass transfer coefficient for SO_2 absorption by spray droplets to be a function of gas flowrate, the Schmidt number, the number of spray nozzles, and the spray droplet diameter. For the case of absorption by a liquid film, they reported K_G to be a function of gas flowrate and the Schmidt number.

Markant, et. al.[45] in their study of a venturi scrubber for absorption of SO_2 by $Mg(HSO_3)_2$ - $MgSO_3$ solutions, developed an empirical relationship that relates venturi SO_2-absorption efficiency to three variables: M, the $MgSO_3$ concentration of the scrubbing solution; T, the total SO_2 concentration of the scrubbing solution; and t, the scrubbing solution temperature. This empirical relation

$$A \cong 117 + 30M - 15T - 0.10t$$

where A is the SO_2-absorption efficiency, can be related back to the mass transfer coefficient through equations like (5) and satisfactory equilibrium data.

Tenertkov,[46] in his investigation of mass transfer coefficients for absorbing SO_2 with lime suspensions in slat and lath towers, showed for a constant Schmidt number that the mass transfer rate was a function of the Reynolds number for the gas phase.

The above examples from the literature indicate the type of data correlations that have been attempted for alkaline scrubbing systems. It is a major purpose of the test program to develop a more complete model, sufficient for full-scale commercial design.

6.2 PARTICULATE REMOVAL

Full scale tests conducted by Combustion Engineering, Inc., at Detroit Edison Company's St. Clair station[47] provided particle size distribution data that can be used to evaluate the particulate removal efficiency of various wet scrubber designs. Table 6-2 shows the estimated particle size distribution based on these tests.

Table 6-2

PARTICLE SIZE DISTRIBUTION DATA

Size Range (Microns)	Weight Percent
< 1	2
1 - 2	3
2 - 5	29
5 - 10	28
10 - 20	12
> 20	26
	100

These data were used in two ways to estimate the efficiency of various scrubber designs. They were given to the manufacturers listed in Table 6-1 as part of a request for their estimate of the efficiency of their scrubbers and were used to calculate efficiencies for specific designs using the method given by Stairmand.[48] The calculation procedure involved using grade-efficiency curves for a specific scrubber to obtain a collection efficiency for a particle size range. This efficiency was then multiplied by the fraction of particles within that size range. The sum of these values for all sample size ranges is the collection efficiency for the scrubber.

The source of the grade-efficiency curves used for each design is indicated where the efficiencies are reported (see Table 6-3).

The calculated and manufacturer-supplied efficiencies were compared with the efficiencies predicted by the contacting-power relation reported by Semrau[49] and Semrau et. al.[50] This relation is based on the concept that removal efficiency can be correlated with the total power dissipated in the scrubbing operation, regardless of the scrubber design or source of power (i.e., gas pressure drop, liquid pressure drop, or mechanical agitation). The contacting power derived from the gas phase is given approximately by the equation

$$(10) \quad P_G = 0.157\,F_s$$

where P_G is the power input and F_s is the friction loss across the scrubber in inches of water. For the scrubbers evaluated, the change in kinetic energy of the gas phase is small, and F_s is essentially equal to the scrubber pressure drop. The relation for the power derived from the liquid phase is given as

$$(11) \quad P_L = 0.583\,P_F\left(\frac{q_L}{q_G}\right)$$

where P_L = the power input

P_L = scrubbing solution feed pressure (lb-force/in.^{2} gauge)

qL = solution feed rate (gal/min)

q_G = gas flow rate (ft^3/min)

The total power dissipated, P_T, can be correlated with the removal efficiency, expressed in particulate transfer units, N_{pt}, by the equation

$$(12) \quad N_{pt} = \alpha P_T \gamma$$

where α and γ are constants that depend on the physical properties of the particulate mixture.

This correlation was only used in a qualitative manner to compare manufacturer-supplied and calculated efficiencies for different designs. The constants α and γ were not evaluated for the particles shown in Table 6-2.

For wet scrubbers, particulate-removal efficiency is usually an exponential function of such variables as input power and pressure drop. Therefore, to facilitate reporting results at high efficiencies where relatively large changes in such variables produce only minor changes in efficiency, the concept of particulate transfer units, N_{pt}, can be used. N_{pt} is defined by

$$(13) \quad N_{pt} = \left(\frac{1}{1 - \eta}\right)$$

where η is the fractional removal efficiency.

In the test facility, the above techniques will be used in reporting the removal efficiencies obtained by direct measurement.

6.3 BASIS FOR SCRUBBER EVALUATION

The wet scrubbers required for the test facility should remove both particulates and SO_2 with high efficiency. Particulate removal efficiency should be on the order of 99-plus percent ($N_{pt} > 5.0$) and SO_2-removal should be better than 85 percent. If possible, the scrubber should also perform as an effective device for dissolving calcium and magnesium oxide.

The preceding sections have described methods for evaluating the SO_2 absorption and particulate removal characteristics of wet scrubbers. These methods have been employed where possible in selecting the scrubbers for testing. However, application of the absorption method on a quantitative basis was not possible because of a lack of basic property data. One of the primary functions of the test program will be the development of such data.

Scrubbers were also selected on the basis of mechanical performance. From observance of the scrubbers installed by Combustion Engineering at Union Electric Company's Meramec Plant and discussions with operating personnel, two major areas of concern are the buildup of solids on the surfaces where hot flue gas first contacts the scrubbing solution, and the plugging in the gas-liquid contacting zone. At Meramec, the latter refers to the plugging of the scrubber bed. At this time, it is believed that both potential problems can probably be avoided by proper design of the scrubber and control of the chemistry (pH, dissolved solids) of the liquid streams.

Combustion Engineering, after modification of the Meramec scrubbers to improve gas distribution across the bed of the scrubber, has been able to operate without bed plugging. The hot flue gas-liquid interface

problem can probably be avoided or minimized by designing the gas inlet as shown in Figures 3-7 and 3-13 in Section 3. These figures show the design of a wet collar in the duct ahead of the scrubber inlet. This collar provides for an abrupt transition between flue gas in contact with a dry duct wall and a wet duct wall.

Experience at Meramec also indicates that plastic coatings can be of aid in controlling plugging and solids buildup on scrubber surfaces. Peabody Engineering Corp.[51] has also stated that the tendency of impingement plates to plug can be reduced by the use of plastic coatings.

Other major mechanical factors considered were:

- Pressure drop
- Ability to operate with slurry feeds
- Compactness of design
- Mist eliminator efficiency
- Turndown capability
- Ease of control
- Maintenance requirements

Other factors used in the selection were the process limitations discussed in Section 4 and the compatability of scrubber and steam-generator operating conditions.

6.4 SCRUBBER DESIGNS EVALUATED

A number of different wet scrubber designs are in use. Certain designs, such as those using packed beds and sieve trays, are basically absorption devices. Others, such as cyclones, venturis, and impingement plates, have been used primarily for particulate removal.

In this section, the various designs considered are briefly discussed and their principles of operation outlined. Table 6-3 summarizes the estimated performance of these designs for the limestone-scrubbing process. Table 6-4 presents the available SO_2 mass transfer data for the various designs.

6.4.1 Cyclone Scrubbers

Cyclone scrubbers vary greatly in design, ranging from simple units equipped with sprays to complex multistage devices. The basic physical principle used for particulate removal is centrifugal force. Generally, gas enters the cyclone tangentially, spirals upward, and exits along the scrubber axis. Vanes may be provided to enhance the spiraling and provide additional surfaces for particle deposition. Liquid is sprayed into the rotating gas as a fine mist and is carried by centrifugal force to the cyclone walls. Enroute, the spray droplets collide with and collect the particulates present in the gas. Exact location of the sprays, as well as design of the spray heads, is important to achieve optimum particulate removal.

Cyclone scrubbers are used primarily for removing relatively large particles: the velocity of the spray droplets is insufficient to collect small particles except at relatively short distances from the spray nozzles. In general, cyclones are not well suited to collect particles below five microns.[52,53]

Cyclones of the most efficient design are not generally considered to be efficient absorption devices, particularly if the resistance to mass transfer is appreciable in either both phases or only in the gas phase.[42] Also, compared with other scrubbers, the amount of interfacial area for mass transfer that can be generated per unit of equipment volume is relatively small. This limitation, however, can in part be reduced by use of a large number of high-pressure spray nozzles. By such a method Johnstone and Silcox[44] were able to obtain SO_2 removal efficiencies of over 85 percent using a 0.6 N sodium carbonate solution.

A further absorption limitation is that the advantages of counter-current operation cannot be realized. The reason for this is that, to obtain as much liquid surface as possible, it is necessary to mount sprays along the axis of the scrubber parallel to the gas flow. With this arrangement, the liquid flow is at approximately a right angle to the gas flow.

A further drawback to the use of cyclones with the solutions or slurries required by limestone scrubbing is potential plugging and wear of the large number of nozzles that would be required.

6.4.2 Spray Towers

This type of scrubber consists of a chamber with downward-directed sprays. As dust containing gas enters the chamber, its velocity is reduced so that larger particles settle out. Additional particle removal results from impingement with liquid droplets.

Spray towers are used primarily for gas cooling and humidity adjustment. They are not considered efficient for the removal of fine particulates (below 10 microns).[52,53]

As mass transfer devices, spray towers have the same general deficiencies attributed to wet cyclones.[42] However, because of less turbulence in the gas phase, and, usually, a smaller number of sprays,

Table 6-3

SCRUBBER PERFORMANCE

Type of Scrubber	Estimated SO_2 Removal Efficiency (%)	Estimated Particulate Removal Efficiency, N_{tp}	Est. Scrub. Liq. Req. gal/1000 ft^3 of inlet gas	Pressure Drop* (Inches H_2O)	Sc in
Venturi	85+ (with absorption section)	$4.0+^{53, 60}$	11 - 17**	6 - 15	
Flooded Bed	90+	$4.0+^{47}$	8 - 11	6 - 10	
Turbulent Contact (2 stages)	85+	$4.0+^{61, 62}$	15 - 30	6 - 10	
Impingement Plate (2 stages)	85+	$4.0^{53, 63, 64}$	8 - 20	7 - 9	g d
Cyclone	70	$2+^{48}$	4 - 10	2 - 5	p
Packed Bed	90+	$3.5+^{59}$	15 - 30	3+	
Nozzle	70	4.0^{65}	--	6+	
Spray Tower	60	1.7^{48}	2 - 5	2+	p
Cross Flow	80	2.0+	6 - 12	4+	

* From scrubber inlet to mist eliminator outlet

** Includes absorption section

*** For a single unit with no partitions

A

Table 6-3

SCRUBBER PERFORMANCE SUMMARY

. Scrub. Liq. ı. gal/1000 ft^3 f inlet gas	Pressure Drop* (Inches H_2O)	Resistance to Solids Plugging in Contact Area	Compactness	Normal Gas Velocity ft/min	Turndown*** Capability (%)
11 - 17**	6 - 15	good	good	10000 - 15000 (throat)	50+
8 - 11	6 - 10	good	good	500 (shell)	35
15 - 30	6 - 10	good	good	850+ (shell)	25 - 35
8 - 20	7 - 9	good if proper design is used	good	500 (shell)	30
4 - 10	2 - 5	poor because of nozzle plugging	poor	2000 - 4000 (inlet)	15
15 - 30	3+	poor	fair	200 - 450 (shell)	30
--	6+	good	good	--	15
2 - 5	2+	poor because of nozzle plugging	poor	200 (shell)	15
6 - 12	4+	poor	good	200 (shell)	15

B

Table 6-4

SCRUBBER EFFICIENCY DATA F

Type of Scrubber	System	Reported SO_2 Remov Efficienci
Flooded Bed (National Dust Hydro-Filter)	Dolomite Injection	90+
Turbulent Contact (UOP Air Correction Division)	5% $CaCO_3$, 5% $NaCO_3$	80 - 83
Packed Bed (Grid Tower) (Mitsubishi Heavy Industries, Ltd.)	$Ca(OH)_2$	90
Packed Bed (Grid Tower) (I. C. I. - Howden & Co.)	Lime and Chalk Slurry	90+
Packed Bed (Grid Tower) (Tenertkov, USSR)	Lime Slurry	96+
Venturi (Chemico)	Lime Slurry	70 - 90+
Venturi (Research-Cottrell)	Hydrated Lime Dust 2N NaOH	70 80
Venturi - Adsorption (Research-Cottrell)	Hydrated Lime Dust	90
Impingement Plate (Peabody Engineering)	5% NaOH	98+
Venturi - Two-Stage (Bahco)	Lime Slurry	98+

A

Table 6-4

SCRUBBER EFFICIENCY DATA FOR SO_2

System	Reported SO_2 Removal Efficiencies	Notes
lomite Injection	90+	Tests at St. Clair;[47] stoichiometric ratio = 110 - 120%
$CaCO_3$, 5% $NaCO_3$	80 - 83	Tests at Oak Creek Plant of Wisconsin Electric Power Co.;[61] liquor rates and gas velocities comparable to those shown in Table 6-3
$(OH)_2$	90	Tests on flue gas from an oil-fired steam generator[58]
ne and Chalk Slurry	90+	Cyclic lime process (British);[59] grid packing
ne Slurry	96+	Reference 46
ne Slurry	70 - 90+	Pilot scale tests;[71] pH range 4 - 7; without absorption section
drated Lime Dust	70	Pilot scale tests[60]
NaOH	80	Pilot scale tests
drated Lime Dust	90	Pilot scale tests;[72] short absorption section after venturi
NaOH	98+	Reference 55
ne Slurry	98+	Tests on gas from an oil-fired steam generator[73]

B

they tend to display these deficiencies to a greater degree. Also, like cyclones, they do not operate in a truly counter-current manner — the momentum of the spray usually being only sufficient to allow thorough mixing for a limited distance.[42]

6.4.3 Impingement-Plate Scrubbers

Impingement-plate scrubbers use kinetic energy to achieve particulate removal. They consist of one or more perforated plates with baffles located directly over and above the perforations. Liquid flows across, and gas through, the plates. In passing through the perforations, the dust-containing gas accelerates to form high-velocity jets. These jets impact or impinge against the baffles, the action transferring particulates from the gas to the liquid. To achieve high efficiency, a number of impingement plates are used.

In the acceleration-impingement process, the gas forms small bubbles, which pass through the liquid on the plates. This generates both a large gas-liquid interfacial area and considerable turbulence. Both effects promote mass transfer.

These scrubbers have been used in small commercial (aboard oil tankers) and pilot operations for removing SO_2 from flue gas.[54, 55] Brief and Oeistad[54] have reported SO_2 removal efficiencies on the order of 96 percent when scrubbing flue gas from an oil-fired steam generator (2 percent-plus sulfur fuel) with seawater in a three-stage unit. The liquid flow rates, however, were quite high relative to what is anticipated for SO_2 removal with lime solutions or slurries.

Another use of impingement scrubbers as absorbers is in the production of neutral sodium-sulfite cooking liquors for pulping by absorbing SO_2 with a soda ash solution.

6.4.4 Packed Bed Scrubbers

A packed bed is a method of increasing gas-liquid interfacial area. Generally, the packing material is either ceramic or plastic, and its shape is such that it provides a large contact-area per unit volume. Gas enters at the bottom and passes upward through the packing. Liquid is sprayed in at the top and passes downward, collecting particulates and absorbing gases before leaving through the scrubber bottom.

Packed beds are usually used for gas absorption rather than particulate removal. Their application is usually limited to removing relatively coarse particulates present in low concentrations.

A considerable amount of work has been done in use of slat, grid, or lath towers for SO_2 removal with lime and limestone solutions and slurries.[46, 56, 57, 58, 59] That of Tenertkov[46] is of particular interest. He used lime slurries (20 to 32 wt. percent) to scrub SO_2 and ash from flue gas in a slat tower with a cross section of 48 ft^2. For gas velocities above 1.25 ft/sec, SO_2 removal efficiencies of 98-plus percent were reported. Mass transfer coefficients from 158.7 kg/m^2 - hr - atm for a gas velocity of 1.25 ft/sec to 584.0 kg/m^2 - hr - atm for a velocity of 4.5 ft/sec were reported.

Mitsubishi Heavy Industries, Ltd., Tokyo, Japan, has also investigated the use of grid towers, in this case with a gas flow rate of 3000 to 5500 scfm.[57, 59] Their results appear to agree with those of Tenertkov. Reported SO_2 removal efficiencies are on the order of 90 percent.

The English work described by Pearson, et. al.[59] is also in general agreement with Tenertkov, removal efficiencies on the order of 90-plus percent being reported. The English also describe the problems associated with equipment scaling. To prevent $CaSO_4$-scaling, they found it necessary to use a delay tank to desupersature, with regard to $CaSO_4$, the slurry exiting the scrubber.

Neither Tenertkov nor Mitsubishi have described in detail their experience with regard to plugging or solids buildup.

6.4.5 Cross-Flow Scrubbers

Cross-flow scrubbers are similar to packed-bed scrubbers in that pieces of ceramic or plastic material are used to generate contact area. However, in the cross-flow scrubber, the scrubbing liquid is fed onto the top of the bed and moves downward, while the gas moves horizontally through the bed. Pressure drop in such a unit is typically about a third of that in a vertical countercurrent column having the same area of gas flow. Lower liquid rates are required than in a vertical column, and plugging problems can be lessened by using sprays to irrigate the inlet section of the packing where most of the particulate removal takes place.

Cross-flow scrubbers provide good collection efficiency for particulates down to 3 microns.[52] They have been used successfully for removing hydrogen fluoride and silicon tetrafluoride from waste-gas produced in the production of phosphate fertilizer. However, no reference to their use for SO_2 removal or with slurries was found.

6.4.6 Turbulent Contact Scrubbers

This type of scrubber utilizes mobile packing to achieve a high gas velocity, relatively low pressure drop, and large liquid-gas interfacial area. The packing consists of low density, plastic spheres free to move between retaining grids. Gas enters at the scrubber base and passes upward through the packing. Scrubbing liquor enters at the top and flows downward. This counter-current gas-liquid flow forces the spheres upward in a random, turbulent pattern, forcing intimate mixing of gas and liquid phases. The degree of bed agitation can be changed by controlling the scrubber liquid-gas ratio.

The device is well suited for applications where both efficient particulate removal and mass transfer are required. It is also suited for operations where precipitates can form or where plugging is a problem. Because of their turbulent motion, the spheres are continuously cleaned by impinging against one another. This effectively controls solids accumulation and bed plugging.

Douglas, et al.,[66,67] have reported both pilot plant and commercial-scale plant data for turbulent contact scrubbers when using a magnesium hydroxide slurry for SO_2 absorption. The pilot unit was 1-foot square by 18-feet high and had three absorption stages with a 10-inch static depth of packing in each stage. The packing was 1.5-inch-diameter hollow polyethylene spheres. The test data are summarized below:

Inlet Gas Flow, ft/min	520
Temp., F	115
SO_2, %	15.6
Exit Gas Temp., F	95
SO_2, %	0.8
$Mg(OH)_2$ Slurry Flow, gpm	38
Recirculation Liquor Flow, gpm	14
Total Liquor, gpm	52
Pressure Drop, in. w.g.	12
Product Liquor Temp., F	115
pH	4.3
SO_2 Pickup, lb/hr-ft^2	670
Recovery Efficiency, %	96.3
Kga lb-mole/hr-ft^3-atm	90

The plant turbulent contact scrubber was a tower two feet in diameter and 20 feet high installed over a sump tank five feet in diameter and six feet high. The tower consisted of four stages, each four feet high and containing 1.5-inch-diameter hollow plastic spheres to a static depth of 15 inches. (15.7 ft^3 total.) Three stages were found adequate to recover SO_2, and the top stage was modified to minimize entrainment. Test data reported were:

Inlet Burner Gas Temp., F	161
SO_2, %	17.5
Volume, ft^3/min	2,900
Exit Gas Temp., F	130
SO_2, %	0
$Mg(OH)_2$ slurry, % solids	20
Flow, gpm	13
Fresh Water, gpm	45
Slurry Temp., F	111
Product Liquor, gpm	67
Temp., F	156
pH	4.3
Total SO_2, %	8.36
Free SO_2, %	4.22
SO_2 Pickup, lb/hr	2,970
lb/hr/ft^2	950
Recovery Efficiency, %	100

Pollock, et al.,[61] have reported on use of a pilot turbulent contact scrubber for removal of SO_2 from flue gas resulting from coal-firing. The pilot unit was 14 inches in diameter, 25 feet high overall, and contained two stages. Removal efficiencies of 85 percent or better were reported for liquid-to-gas flow ratios (lb/min-ft^2) above 11.0 when using a 5-percent $CaCO_3$ slurry. For a liquid-to-gas ratio of 11.0, the pressure drop across the scrubber was approximately seven inches of water. Tests were also made using $Ca(OH)_2$; however, no results were reported for this absorbent.

6.4.7 Flooded Bed Scrubber

These units consist of a vertical shell housing a shallow (2- to 2-1/2-in.) bed of glass marbles, a set of liquid sprays, and dewatering vanes. Flue gas enters beneath the bed and turns sharply upward, dropping out larger particulates. Liquid sprays upward against the underside of the bed and is pulled through the bed by entrainment in the gas stream.

Mixing and bubble formation within the bed create a highly turbulent layer extending perhaps six inches above the bed. This layer provides the primary contacting mechanism for both particulate removal and mass transfer of gas to liquid. Liquid leaves the bed area through an adjustable-height drain that extends up into the turbulent layer. Cleaned gas passes a mist eliminator before leaving at the top of the scrubber.

A combination of liquid flooding and gentle movement of the marble bed provides a self-cleaning action. Another important characteristic of this bed design is its ability to operate at high liquid to gas ratios without loss of efficiency. Effective removal of 2-micron particles is reported.[68, 69]

These scrubbers are being used by Combustion Engineering, Inc., for SO_2 removal from flue gas by the same process to be investigated in the planned Detroit Edison test facility. The reported results of their pilot studies[47] include SO_2 removal efficiencies of 90-plus percent when injecting a stoichiometric quantity of dolomite into the steam generator. Pressure drop ranged from six to eight inches of water.

Currently, Combustion Engineering is operating full-scale units at power plants of Union Electric Company and Kansas Power and Light. To date, operation of these units has been confined to the solution of various mechanical problems. As far as is known, no actual performance data for these units has been reported.

6.4.8 Venturi Scrubbers

In venturi scrubbers, particulate-laden gas is accelerated to high velocity in the throat section of a venturi. At the point of maximum velocity, liquid is introduced into the gas stream where it is atomized by the velocity of the gas into a fine spray.

Since the spray-droplet velocities are considerably lower than the gas velocity, particulates impact on and are collected by the droplets. As the gas decelerates, these droplets agglomerate and are removed downstream of the venturi.

To prevent solids buildup in the inlet section of the venturi, liquid flow down the venturi throat walls can be employed. This flow can be achieved by an overflow weir at the venturi entrance.

The efficiencies reported by Markant, et al.,[45] for a single-stage venturi scrubber are generally supported by information obtained in discussions with Research-Cottrell, Inc. From these results, it is believed that, to obtain efficiencies better than 85 percent, either two stages are required or additional surface for mass transfer must be provided after the venturi; i.e., a combination-type of scrubber must be utilized (see Figure 3-5). Use of a venturi in combination with packing, a flooded bed, a turbulent bed, or impingement plates could be advantageous for the process under consideration. The possible advantages are discussed in Section 6.5.

6.4.9 Nozzle Scrubbers

In a nozzle-type scrubber, gas impinges at high velocity on a stagnant pool of liquid. High gas-velocity is achieved by means of an orifice with an outlet usually slightly below the surface of the liquid. The gas keeps the liquid agitated and induces a spray. The primary mechanism for particulate removal is impingement of the particulates on the induced spray. No references were found regarding use of this type of scrubber for absorption.

An alternative configuration for a venturi is to have the liquid sprayed onto a plate with the gas passing downward through an annulus between the plate and the scrubber shell.[70] This design gives a finer dispersion of the liquid droplets than the conventional-type venturi.

Markant, et al.,[45] have investigated the performance of a pilot venturi scrubber when used to absorb SO_2 with magnesium sulfite-bisulfite solutions. For combustion gases containing about one percent SO_2, removal efficiencies ranging from 32 to 77 percent were reported. (The effect of certain operating variables on removal efficiency was noted on page 6-8.) The reported results indicate that both solution sulfite and total SO_2 concentration have a significant effect upon removal efficiency.

Markant, et al., also describe briefly a commercial system, installed in a Swedish pulp mill, in which two stages of venturi scrubbing are used to remove 95 percent of the SO_2 present in flue gas initially containing about one percent SO_2. The scrubbing medium used in this system is a $Mg(OH)_2$ slurry.

6.5 RECOMMENDED SCRUBBER DESIGNS

Scrubbers recommended for evaluation in the test facility are:

- A venturi scrubber followed by an absorption section
- A turbulent-contact scrubber
- A flooded-bed scrubber
- An impingement-plate scrubber

It is recommended that three testing modules be used for evaluation. One of these would be designed to permit interchange between flooded-bed and impingement-plate types. The other two would be designed for evaluation of various venturi-absorption and turbulent-contact scrubber configurations. For instance, in the case of the turbulent-contact scrubber evaluation, both two- and three-stage configurations would be possible.

6.5.1 Venturi Scrubber and Absorption Section

A venturi design is recommended because:

- It can achieve satisfactory particulates removal at acceptable pressure drops (five to ten inches of water).
- It has been used successfully on lime kilns, a service similar to alkali scrubbing.
- It is used for the recovery of SO_2 from spent cooking-liquor in the Magnefite pulping process by absorption of SO_2 in a $Mg(OH)_2$ slurry.
- It is relatively easy to control.
- It can be designed to operate efficiently at a relatively high turndown (50 percent).
- Its operation with slurry recycle has been demonstrated.

- The hot gas-scrubbing liquor interface problem is easily solved by a wetted-wall design.
- Compact equipment design is possible.

The largest area of doubt with regard to use of a venturi is its mass transfer capabilities. Tests using dolomite and limestone, which have been calcined under conditions similar to those expected in a steam generator and where the additive enters in the gas rather than the liquid phase, are inconclusive. Therefore, it is recommended that a short, removable absorption section be provided after the venturi exit. This would allow evaluation of both venturi and venturi-absorption scrubbers. With the absorption section in operation, the scrubber could be operated in two ways:

1. Scrubbing solution or slurry of the same composition could be fed to both the venturi throat and the absorption section, with removal of a combined solution at the scrubber base (see Figure 3-5).
2. Scrubbing solution or slurry could be fed from the process water hold tank to the absorption section only, with the spent solution or slurry from this section being collected separately from the venturi effluent and sent to the venturi throat.

Scheme 2 may be the most advantageous since it could allow separation of the particulate removal and slaking operation from that of SO_2 removal. In this scheme, the solution or slurry fed to the absorption section would have a relatively high sulfite concentration, a condition favoring SO_2 absorption, and the solution or slurry fed to the venturi throat would have a relatively high bisulfite concentration, a condition favoring the dissolution of the calcined additive. Also, with this scheme, the conditions for slaking outside of the scrubber would probably be better, because of a higher bisulfite concentration in the venturi-section effluent. Thus, if the rate of additive dissolution is a critical factor in this process, the venturi-absorption scrubber may have a unique advantage over other designs.

A possible further advantage of the combination unit is that the particulate concentration of the gas fed to the absorption section would be relatively low and, hence, the susceptibility to plugging in this sectiom may also be low. This would be particularly true where a clarified solution is fed to the absorption section.

Several designs could be used for the absorption section: a packed bed, a mobile bed, or an impingement plant. Actual design recommendations will be made during Phase II of the study.

Presently, four scrubber manufacturers are recommended as potential suppliers of a venturi-absorption scrubber. These are Chemical Construction Corporation, Research-Cottrell, Inc., Universal Oil Products Air Correction Division, and Babcock & Wilcox Company. Development of the specifications required for supplier selection would also be accomplished during Phase II.

6.5.2 Turbulent-Contact Scrubber

The turbulent-contact scrubber is recommended because:

- It provides high gas absorption and particulate removal efficiency at reasonable pressure drop (six inches to ten inches H_2O).
- It is capable of high gas rates (2,800 ft/min), permitting design of a compact unit.
- Scrubber liquor requirements are modest (10-15 gal/1000 acf).
- Liquid is sprayed through low-pressure nozzles, which are not very susceptible to plugging
- The agitation of the bed keeps the spheres clean, thus preventing plugging of the absorption area.
- It has been demonstrated on a small scale to be capable of removing SO_2 and particulates from flue gas using lime and limestone slurries.

- It has been used successfully to remove SO_2 from recovery-boiler flue gas in the pulp industry, using $Mg(OH)_2$ slurries.
- Maintenance requirements are minimal. Replacement of the bed when and if required is quite easy.

The only anticipated operating difficulty of the turbulent-contact scrubber would be the possible solids deposition at the hot gas and liquid interface at the gas inlet. This problem can probably be solved by proper design of the inlet duct.

The only manufacturer of turbulent-contact scrubbers is Universal Oil Products Air Correction Division.

6.5.3 Flooded-Bed Scrubber

The flooded-bed scrubber is recommended because:

- It has high gas absorption and particulate removal efficiency at reasonable pressure drop (six inches to ten inches H_2O).
- It has reasonable liquor requirements 10-15 gal/1000 acf).
- Gas flow rates, although lower than for the turbulent-contact scrubber (500 ft/min), are still high when compared to spray or conventional packed towers.
- Liquid is sprayed through low-pressure nozzles which are not very susceptible to plugging.
- Adequate particulate removal and gas absorption can, it is anticipated, be achieved in one stage.
- The constant, slow movement of the bed has a self-cleaning effect.
- It has low maintenance requirements.
- It was been successfully used in pilot studies of the injection-wet scrubbing process.

- It is currently being used in full-scale alkali scrubbing systems (Combustion Engineering, Inc., Air Pollution Control System).

The only anticipated operating difficulty of the flooded-bed scrubber would be possible solids deposition at the hot gas and liquid interface encountered at the gas inlet. This problem can probably be overcome by proper design of the inlet duct.

Combustion Engineering, Inc., is the recommended supplier of this scrubber. The manufacturer is the National Dust Collector Corporation.

6.5.4 Impingement-Plate Scrubber

The impingement-plate scrubber is recommended because:

- It is an efficient gas absorption and particulate removal device and operates at a reasonable pressure drop (five inches to ten inches H_2O).
- Although it may be more susceptible to plugging than the other three recommended scrubbers, the plugging may be alleviated by the use of plastic or plastic-coated trays.
- It operates at the same gas velocity as the flooded-bed scrubber, thus permitting the unit to be tested by simply replacing the internals of the flooded-bed scrubber.
- Liquor enters through low-pressure sprays and an overflow weir, thus minimizing plugging problems in these areas.
- It has been demonstrated in services — lime kilns, oil-fired-steam-generator flue-gas scrubbing, and flue-gas caustic scrubbing — similar to alkali scrubbing.

Two scrubber manufacturers are recommended as potential suppliers of this scrubber design. These are Peabody Engineering Corporation and Arco Industries Corporation.

6.5.5 Mist Eliminators

Two types of mist eliminators are recommended. One is the chevron type, consisting of stainless steel vanes, on which entrained liquid droplets impinge to flow downward and horizontally to a drain. Water removal efficiency is constant with this type, over a wide range of gas rates. It is recommended for the flooded-bed and turbulent-contact scrubbers. The second type of mist eliminator recommended is a centrifugal device, consisting of vanes that force the rising gas against the scrubber shell. The entrained liquid impinges against the shell wall and flows downward back into the scrubber. It is anticipated that this type of mist eliminator will be used with the venturi and impingement-plate units. A final decision will be made during Phase II as to whether the vane-type mist eliminator used in the flooded-bed scrubber will be changed to a centrifugal mist eliminator when the flooded-bed scrubber is converted to the impingement-plate type.

6.5.6 Gas Inlet Section

The gas inlet section of the scrubbers is also important. This is an area where solids buildup can occur due to the hot gas and liquid interface. For the venturi, impingement-plate, and flooded-bed units, wetted wall entrances are recommended. This can be accomplished by use of an overflow weir that wets the inlet wall. The water flowing down the walls will prevent solids from depositing and will also partially humidify the inlet gas. For the turbulent-contact unit, a large rectangular inlet nozzle is recommended. The intent of this nozzle is to create a sharp interface at the point at which hot gases contact scrubbing liquid. Nozzles would be provided to wash any areas where gas velocities would be low, such as close to the scrubber wall.

6.6 SCRUBBER DESIGNS ELIMINATED

Packed-bed and cross-flow scrubbers were not selected because of their tendency to plug when handling slurries or solutions from which solids precipitate. The supersaturation-desupersaturation characteristics of calcium sulfate solutions could lead to a particularly severe plugging problem with these scrubbers. However, operation of the selected scrubbers at the test facility will result in a better understanding of solids precipitation. This will permit further consideration of packed-bed and cross-flow scrubbers.

Cyclone scrubbers and spray towers were eliminated because they do not efficiently remove particles smaller than 10 microns and do not provide an effective gas-liquid contactor for SO_2 absorption. These scrubbers require high-pressure nozzles for fine liquid dispersion. Such nozzles are susceptible to plugging — a definite possibility in a system handling slurry or a solution that precipitates solids.

Nozzle-type scrubbers are probably not efficient SO_2 removal devices because of the short time available for gas-liquid contact. Also, since all the energy required for spray generation must be provided by the gas, high pressure-drops are required to achieve efficient particulate removal.

Table 6-5

SCRUBBER EVALUATION SUMMARY

Data Required for Evaluation of Scrubber Design		Intended Use of Data	Data Now Possessed
SO_2-Removal Capabilities	1. Actual efficiencies for process on sufficient scale for scale-up to 1000,000 acfm and their relation to process operating conditions	Selection of designs and establishment of operating-condition limits for test facility	a) For ND hydrofilter (single stage and small scale), SO_2 removal efficiency as a funcion of stoichiometric injection rate (dolomite), gas flowrate, liquid flowrate, scrubber effluent pH, use of a mixing tank, and operating time b) For TCA (two-stage, small scale, without injection), SO_2 removal efficiency as a function of gas flowrate and liquid flowrate c) For TCA (3 stages and small scale MgOH slurry, 15.6% SO_2 inlet gas), SO_2 removal efficiency for one set of operating conditions d) For TCA (3 stages, full scale, MgOH slurry, 17.5% SO_2 inlet gas), SO_2 removal efficiency for one set of operating conditions e) For slat tower (4.5m^2 cross section, lime slurry), SO_2 removal efficiency as a function of gas flowrate and pH f) For venturi (small scale, MgOH slurry, 1%-plus SO_2 inlet gas), SO_2 removal efficiency as a function of solution $MgSO_3$ conc., solution total SO_2 conc. and solution temperature

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Table 6-5

SCRUBBER EVALUATION SUMMARY

Data Now Possessed	Data Still Needed	What Test Program Will Determine
or ND hydrofilter (single stage and mall scale), SO_2 removal efficiency as funcion of stoichiometric injection ate (dolomite), gas flowrate, liquid lowrate, scrubber effluent pH, use of a mixing tank, and operating time or TCA (two-stage, small scale, with- ut injection), SO_2 removal efficiency s a function of gas flowrate and liquid lowrate or TCA (3 stages and small scale gOH slurry, 15.6% SO_2 inlet gas), SO_2 emoval efficiency for one set of opera- ing conditions or TCA (3 stages, full scale, MgOH lurry, 17.5% SO_2 inlet gas), SO_2 emoval efficiency for one set of opera- ing conditions or slat tower (4.5m^2 cross section, ime slurry), SO_2 removal efficiency s a function of gas flowrate and pH or venturi (small scale, MgOH slurry, %-plus SO_2 inlet gas), SO_2 removal fficiency as a function of solution $MgSO_3$ onc., solution total SO_2 conc. and solu- ion temperature	For the scrubber designs discussed in Section 6.4, SO_2 removal efficiences and their relation to scrubber operating conditions on a scale sufficent for scale-up to 100,000 acfm units	For the four selected scrubbers: a) Direct measurement of SO_2 removal efficiency for a range of operating conditions b) Correlation of efficiency with scrubber operating conditions at steady state and during changes in operating conditions (gas flowrate, inlet-gas SO_2 concentration, inlet-gas temperature, inlet-gas additive-ash concentration, additive-ash size consist, liquid/slurry feed flowrate, liquid/slurry feed chemical composition, liquid/slurry feed solids concentration, pressure drop, scrubber liquid/slurry distribution)

B

Table 6-5 (Continued)

SCRUBBER EVALUATION SUMMARY

	Data Required for Evaluation of Scrubber Design	Intended Use of Data	Data Now Possessed
SO_2-Removal Capabilities	OR 2. Gas phase/liquid phase equilibrium data for the following solutions for: P_{SO_2} between 2.0 mm 0.05 mm of Hg P_{CO_2} below 120 mm of Hg P_{O_2} below 45 mm of Hg in the temp. range 85-120 F with the inclusion of pH data: a) Ca bisulfite saturated with sulfite and with sulfate levels up to saturation b) Solution (a) in which Mg is present in a ratio of 1 to 1 to Ca and below	Calculation of N_{tOG} for SO_2 removal efficiencies above 85%, determination of the maximum amounts of CO_2 and O_2 that would be absorbed, determination of possible amounts of Ca or Mg that would be lost as $CaCO_3$ or $MgCO_3$	a) Ca bisulfite solutions saturated with sul fite (1) Conrad and Beuschlein, 40 mm of H and above at 15 and 25 C (2) Kuzminykh - Babushkina, 20 mm of Hg and above at 4.5, 15, 25, 50, an 60 C (3) Ternertkov, pH vs. P_{SO_2} from O - 2.3 mm of Hg, solution compositio uncertain, data based on others wor b) Mg bisulfite solutions not saturated with sulfite (1) Markant, McIlroy, and Matty, 0.54 mm and above at 100, 120, and 140 F c) Mg bisulfite solutions saturated with sul fite and containing $MgSO_4$ (1) Pinaev, 0.03 - 0.3 mm of Hg at 30, 40, 50, and 60 C and 50, 80, 100 and 120 g/l $MgSO_4$ (gives pH values)

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Table 6-5 (Continued)

CRUBBER EVALUATION SUMMARY

Data Now Possessed	Data Still Needed	What Test Program Will Determine
) Ca bisulfite solutions saturated with sulfite (1) Conrad and Beuschlein, 40 mm of Hg and above at 15 and 25 C (2) Kuzminykh - Babushkina, 20 mm of Hg and above at 4.5, 15, 25, 50, and 60 C (3) Ternertkov, pH vs. P_{SO_2} from O - 2.3 mm of Hg, solution composition uncertain, data based on others work) Mg bisulfite solutions not saturated with sulfite (1) Markant, McIlroy, and Matty, 0.54 mm and above at 100, 120, and 140 F) Mg bisulfite solutions saturated with sulfite and containing $MgSO_4$ (1) Pinaev, 0.03 - 0.3 mm of Hg at 30, 40, 50, and 60 C and 50, 80, 100 and 120 g/l $MgSO_4$ (gives pH values)	All information described under "Data Required for Evaluation of Scrubber Design"	None: data to be determined in laboratory not at test facility

B

Table 6-5 (Continued)

SCRUBBER EVALUATION SUMMARY

	Data Required for Evaluation of Scrubber Design	Intended Use of Data	Data Now Possessed
SO_2-Removal Capabilities	3. Mass transfer coefficients for the scrubber designs discussed in Section 6.4 and their relation to scrubber operating conditions for SO_2, CO_2, H_2O, O_2 for the solutions described in (2), particularly for solutions saturated with sulfite containing sulfate	Calculation of H_{tOG}'s equipment size and number of stages, determination of CO_2 and O_2 absorption and H_2O transfer to the gas phase, determination of the actual amounts of Ca or Mg that would be lost as Ca CO or $MgCO_3$, calculations of SO_2-removal efficiencies as a function of operating conditions	a) For grid towers, K_G data for lime slurries as a function of gas flow rate and pH (Tenertkov) b) For small venturi scrubber for $Mg(OH)_2$ slurry, a form of mass transfer coefficient as a function of gas flow rate, $MgSO_3$ concentration scrubber feed, total SO_2 conc. scrubber feed, and feed temperature (Markant, et al) at 1.0% SO_2 conc. c) For pilot unit and commercial TCA, K_Ga for $Mg(OH)_2$ under one set of operating conditions at high (15.6 and 17.5%) SO_2 concentrations d) For grid tower (small scale), one set of operating conditions K_Ga (Higashi, et al)
Particulate-Removal Efficiency	4. Particulate removal efficiencies for flyash, calcined additive mixtures as a function of operating conditions	Selection of scrubber designs and establishment of operating condition limits for test facility	a) Grade efficiency curves b) Vendor reports for similar particle size consist, properties, and operating conditions c) Contacting power relation d) Results of actual tests on steam generators (CE, UOP, Chemico) e) General correlations of efficiency and scrubber operating conditions

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Table 6-5 (Continued)

SCRUBBER EVALUATION SUMMARY

Data Now Possessed	Data Still Needed	What Test Program Will Determine
For grid towers, K_G data for lime slurries as a function of gas flow rate and pH (Tenertkov) For small venturi scrubber for $Mg(OH)_2$ slurry, a form of mass transfer coefficient as a function of gas flow rate, $MgSO_3$ concentration scrubber feed, total SO_2 conc. scrubber feed, and feed temperature (Markant, et al) at 1.0% SO_2 conc. For pilot unit and commercial TCA, K_Ga for $Mg(OH)_2$ under one set of operating conditions at high (15.6 and 17.5%) SO_2 concentrations For grid tower (small scale), one set of operating conditions K_Ga (Higashi, et al)	With the possible exception of grid towers, all information described under "Data Required for Evaluation of Scrubber Design"	a) Calculation from material balances of K_Ga for a range of test-facility operating conditions b) Correlation with scrubber operating conditions (for conditions see "What Test Program Will Determine" for (1)
Grade efficiency curves Vendor reports for similar particle size consist, properties, and operating conditions Contacting power relation Results of actual tests on steam generators (CE, UOP, Chemico) General correlations of efficiency and scrubber operating conditions	None	a) Direct measurement under test-facility operating conditions b) Correlation with scrubber operating conditions (gas flowrate, liquid flowrate, additive-ash concentration, additive-ash size consist, pressure drop, liquid distribution)

B

Table 6-5 (Continued)

SCRUBBER EVALUATION SUMMARY

	Data Required for Evaluation of Scrubber Design	Intended Use of Data	Data Now Possessed
Mechanical Performance	5. Susceptibility to plugging under anticipated operating conditions	Selection of scrubber designs and establishment of operating condition limits for test facility	a) Vendor reports for similar services b) Experience of CE with ND hydrofilter at Union Electric Co's Meramac Plant c) Results of pilot tests on steam generators with lime slurries (UOP, Chemico, Howden - ICI, Mitsubishi)
	6. Susceptibility to solids accumulation at hot-flue-gas/scrubbing solution interface	Selection of scrubber and inlet duct design and establishment of operating condition limits for test facility	a) Vendor discussions b) Experience of CE with ND hydrofilter at Union Electric Co.'s Meramac Plant

Abbreviations	CE	-	Combustion Engineering, Inc.
	UOP	-	Universal Oil Products, Air Correction Division
	Chemico	-	Chemical Construction Corporation
	ND	-	National Dust Collector Corporation
	TCA	-	Turbulent Contact Absorber (manufactured by UOP Air Correction Division)
	Howden	-	Jus. Howden & Company, Ltd.
	I. C. I.	-	Imperial Chemical Industries, Ltd.
	Mitsubishi	-	Mitsubishi Heavy Industries, Ltd.

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Table 6-5 (Continued)

RUBBER EVALUATION SUMMARY

Data Now Possessed	Data Still Needed	What Test Program Will Determine
Vendor reports for similar services Experience of CE with ND hydrofilter t Union Electric Co's Meramac Plant Results of pilot tests on steam generaors with lime slurries (UOP, Chemico, Howden - ICI, Mitsubishi)	Plugging susceptibility of large-scale scrubbers as a function of time and operating conditions	a) Determination of the causes of pluggage b) Determination of methods to avoid or control pluggage (both design modifications and operating condition limits)
Vendor discussions Experience of CE with ND hydrofilter t Union Electric Co.'s Meramac Plant	Operating experience with large-scale designs	a) Investigation of methods to avoid or control solids accumulation at hot-flue-gas/scrubbing solution interface
on tured		

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Section 7

UTILITY SELECTION

The ultimate responsibility for selection of the power plant site was reserved by NAPCA for the Government.

The evaluation criteria used for selection of the electric utility and identification of the most suitable power plant were as follows:

Electric Utility

- Service territory and generating stations in or near a major metropolitan area
- Incentive and interest of top management and key operating personnel in program participation
- Possible offers of test assistance
- Politico-economic environment for air pollution control
- Power system of size adequate to allow essentially unrestricted operation of the test facility
- Previous experience and qualification in power generation development programs
- A clear future stake in using coal as a prime fuel

Power Station

- Pulverized-coal-fired over 90 percent of use time; if secondary fuel, preferably high-sulfur-residual fuel oil
- Coal readily available to the station in the range of from 2.0 percent to above 3.0 percent sulfur content

- Coal of different ash contents readily available to the station to enable studies of ash fusion and slagging, as well as flue-gas dust loading and process removal efficiencies
- Coal handling and storage equipment sufficient for segregation of special test burns
- Ready availability of limestone-dolomite from several suppliers
- Feasibility of using station storage, bunkers, and pulverizer capacity for grinding of limestone-dolomite additives
- Multi-unit boiler and turbine generator station
- Feasibility of nearly base-load operation of boiler during test periods, with other parts of the station or system capable of handling fluctuations in load
- Feasibility of cut-ins and other boiler modifications consistent with station operating schedule
- Adequate boiler access for test alkali injection and sampling program
- Existing air preheaters and electrostatic precipitators, feasibility of dry alkali injection and dust collection with existing equipment
- Existing wet or dry ash handling systems and disposal methods, including furnace bottoms
- Arrangements for field offices, control lab, and maintenance shop facilities and possible supporting services
- Arrangements for shift operating and maintenance labor supporting services
- Adequate existing water and waste disposal facilities, with particular attention to disposal of gypsum fly ash slurries
- Suitability of existing equipment arrangements and supporting steel and foundations for test facility installation

Detroit Edison's St. Clair Power Plant, and within it specifically Unit 1, was selected by NAPCA as the site for the test program. Particular advantages of the selection are reiterated:

- Detroit Edison Company has a vital interest in air pollution control, as its coal-burning power plants are close to metropolitan areas and coal of a relatively high sulfur content is the basic fuel.
- The unit selected has available a standby mill that is suitable for limestone introduction, having a row of burners above the burners of the other pulverizers. This will assure lower calcination temperature and reduced dead burning.
- There is adequate space available in the area around the selected unit, so that the scrubbers and all auxiliary equipment, including waste handling equipment, can be accommodated without any interference with other plant equipment.
- There is a simple and logical way to introduce limestone into the existing coal-handling system, and a separable coal bunker section is available to store the limestone.
- A limestone storage area is available close to the coal yard where bulldozers can handle the material.
- Detroit Edison's St. Clair plant was the site of previous small-scale limestone scrubbing experiments; plant personnel are therefore familiar with such operations.

The selected plant has some disadvantages:

- St. Clair has a dry ash removal system. In order to tie into it, the ash slurry removed from the scrubbers has to be dewatered to a 70-percent solids consistency. This requires additional equipment.
- Strict water pollution regulations prevent the drainage of any untreated waste water into the St. Clair River.

General arrangement of the test equipment at the St. Clair plant is shown on the Plot Plan, Figure 3-1.

Section 8

ADDITIVE HANDLING

8.1 QUALITY AND QUANTITY REQUIREMENTS

It is expected that a variety of additives will be tested during the test program. These additives will be limestone and dolomite, from various sources.

It is assumed that the limestone will arrive pre-crushed into 3/4-inch size and delivered by 10-ton, self-dumping trucks. However, shipments of limestone or dolomite may arrive by train, if truck delivery is impractical because of distance to the quarry. Existing dock facilities at the plant site will also permit additive delivery by barges during the months when ice does not interfere with navigation on the St. Clair River.

The quantity of limestone required will depend: 1) on the sulfur content of the coal, 2) on the load of the boiler, and 3) on the desired stoichiometric ratio. Assuming 3-percent sulfur content and full load, the maximum stoichiometric ratio that can be obtained with limestone is 2.7. With dolomite, this ratio is slightly above 2.9. The ratio is limited by the grinding capacity of the pulverizer. To accommodate the high stoichiometric ratio during the test program, additive handling equipment is sized for a minimum rate of 15 tons per hour. While the storage capacities are evaluated for this same high feed rate, it must be realized that during the test program limestone or dolomite consumption will average a much lower rate. This lower rate will depend on the unit load factor and on the average stoichiometric ratio contemplated for the test program.

With a 75-percent boiler load factor, a 1.5 average stoichiometric ratio, and a 3-percent average sulfur content, the average limestone feed rate will be 358 tons per stream day. For dolomite, the same assumptions yield a rate of 303 tons per stream day.

8.2 SOURCES

Preliminary inquiries to local suppliers revealed that an acceptable grade of limestone (90 percent or better $CaCO_3$) is available at Rogers City, Michigan. Another quarry at Presque Isle, Michigan, can furnish 97-percent-$CaCO_3$ limestone. Both of these sources are about 250 miles north of St. Clair; both are close to the lake and are equipped for barge shipping. Regular barge delivery can be scheduled between May 1 and December 1. For the winter months, unless adequate storage facilities were to be constructed, delivery would have to be made by land.

The price for 3/4-inch and smaller Rogers City and Presque Isle precrushed limestone is about $1.25 per ton at the quarry. Delivered to the St. Clair dock, the cost would probably be between $2.00 and $3.00 per ton. Nonbinding quotations were received of from $1.80 to $3.50 per ton. The Presque Isle quarry can also supply limestone with a 5-percent $MgCO_3$ content, at a delivered cost about the same as for pure limestone.

The nearest source of dolomite is the Ohio Lime Company quarry at Woodville, Ohio, 100 highway miles from the St. Clair plant. This stone has an average composition of 44 percent $MgCO_3$ and 54 percent $CaCO_3$. Approximate cost at the quarry is $1.50 per ton. Delivered by truck to the plant site, it would cost between $3.00 and $4.00 per ton.

Section 9

SLURRY HANDLING AND SOLIDS DISPOSAL

The slurry handling and solids disposal systems have three major objectives: (1) to produce recycle scrubber process-water with ranges of flow rates and suspended solids concentrations as required for the experimental program, (2) to separate the solids from the scrubber effluent in a form suitable for disposal, and (3) to remove the solids from the plant to an ultimate disposal site.

The characteristics of the scrubber effluent are of primary importance. These characteristics depend directly on the following:

- Amount and type of alkali (limestone or dolomite) injected into the steam generator
- Flowrate and suspended solids concentration of the scrubber process water influent
- Type of scrubber and related chemical and physical reactions

While the first two items are controllable and may be specified directly, the effects of the third can be only approximately predicted. This fact limits the generality of some of the data presented in the following paragraphs.

9.1 BASIS

9.1.1 Environmental Pollution Potential

Both the slurry handling and the solids disposal systems represent potential sources of objectionable discharges to the environment. Since the slurry handling system is a closed system employing complete recycling of process liquids, only occasional shutdown for maintenance or emergency can result in release of such liquids. The pollution potential of the solid waste disposal system lies in the effects of leachate from the landfill pit. This leachate, as well as shutdown discharges, could carry significant amounts of calcium and magnesium sulfate, sulfite, and carbonate into nearby streams or lakes.

Appendix C discusses further the subject of environmental pollution.

9.1.2 Flowrate and Composition of Scrubber Effluent

The flowrate of the scrubber effluent will vary from 500 to 2000 gpm for the impingement plate and flooded bed scrubbers, with a maximum of 3500 gpm for the venturi-type scrubber. Total suspended solids are expected to range from 5000 to 100,000 milligrams per liter. The dissolved solids include sulfites and sulfates of calcium and magnesium in concentrations of from 4000 to 400,000 milligrams per liter total dissolved solids. These compounds, along with carbonates, hydroxides, and fly ash, are also found in the suspended solids.

Slurry pH is expected to vary from 5 to 8, depending on the operating conditions.

A constraint is placed on the scrubber process-water influent in that the suspended solids concentration should be variable with a low value of about 200 to 300 milligrams per liter.

9.1.3 Particle Size Distribution

The crystals formed in the gas-solid phase process will be small, probably on the order of one micron. The turbulent agitation occurring in the impingement plate and bed scrubbers tends to agglomerate these crystals and the fly ash particles to larger sizes. The venturi scrubber is expected to introduce somewhat lower shear forces than the other types, resulting in a slurry with a larger fraction of material in the very fine sizes (less than 20 microns). The amount of applied scrubber process-water and its concentration of suspended solids are also factors that directly affect particle size distribution. Thus, larger fractions of fines are expected with high flowrate and low influent suspended-solids concentration.

A continuous formation and breakup of scale is expected to take place on the scrubber walls and internal scrubber dividers. This scale will result in discharges of large-size, discrete particles, chunks, and flakes at intermittent intervals. The amount of such material is expected to be minor (less than one percent of the total solids discharged), but could be significant from the standpoint of plugging lines and upsetting normal operation.

9.1.4 Settling, Filtration, and Centrifuging Characteristics

Settling, filtration, and centrifuging characteristics depend on the particle size distribution, the physical form and surface characteristics of the particles, and their electrochemical activity (zeta potential). The variation in mode of operation and scrubber design is expected to result in a wide range of such characteristics. Experience from the similar alkali-scrubbing facility at Union Electric Company's Meramec Plant appears to substantiate that relatively high settling efficiencies can normally be realized. The clarifier at that installation is a 75-foot-diameter tank, with a design flowrate of 1475 gpm, corresponding to a loading of 0.339 gpm per square foot. Operational experience has indicated that this loading is too low. The manufacturer of the clarifier, EIMCO, has indicated that a loading of 0.75 gpm per square foot would be expected to produce 200 to 300 milligrams per liter of suspended solids in the overflow and 30 percent of solids by weight in the underflow.

EIMCO has also performed limited filtration tests on samples from this installation and has found that a loading of 75 pounds per square foot per hour would be suitable for the design of vacuum filters. This is a relatively high loading, typical of easily dewatered materials. The tests did not indicate that filter blinding would become a significant problem. However, since the tests were performed on samples several days old, it would seem likely that the slurry could have become stabilized with respect to the supersaturated and flocculating constituents that cause blinding. Such stabilization cannot be reached in actual operation. Also, the Union Electric Meramec facility is normally operated with alkali injection rates near stoichiometric amounts, resulting in minimal available amounts of such blinding material as calcium carbonate. For the facility contemplated at St. Clair, it would thus appear necessary to assume that significant filter blinding can occur.

Centrifuging would appear to be an effective method for slurry dewatering, particularly since blinding does not occur in such operations. The fly-ash component of the solids contains aluminum silicate and other abrasive materials, which represent potential sources of upsets for such high-speed machines as centrifuges. The mixture of these abrasives with the calcium and magnesium compounds that will be encountered can easily be handled, however, with suitable hard-metal lining for the exposed parts of the centrifuge.

9.1.5 Cementitious Properties

Studies have been carried out at West Virginia University School of Mines on the cementitious properties of limestone-modified fly ash, which would presumably have chemical and physical characteristics similar to the solids produced in the St. Clair scrubbing process. These studies indicated that a compressive strength of 100 to 300 psi could be developed over a settling period of less than two weeks. This indicates that the slurry-handling system should be designed to minimize solids buildup anywhere in the system and to incorporate facilities for immediate flushing of all lines and equipment following shutdown.

9.1.6 Corrosion Potential

The slurry corrosion potential (such as that measured by the Langlier Index) cannot be ascertained without experimental data. It may, however, be anticipated that SO_2 will be present in amounts sufficient to cause severe corrosion under some modes of operation. The choice of material for pipelines and equipment reflects this possibility.

9.2 METHODS CONSIDERED

9.2.1 Slurry Handling

Several types of solids/liquid separation methods may be applicable to the effluent produced in the wet scrubbing process. The more important methods will be reviewed briefly.

Sludge-Contact Clarifiers. Sometimes called thickeners, these solids/liquid separators commonly consist of a circular settling tank with submerged center inflow, rim overflow, and scrapers moving on the tank bottom to transfer settled sludges to a center outlet. A reasonably well defined interface between clear liquid and upflowing slurry is formed, near which small particles may come in contact with other particles and agglomerate to sizes large enough to settle out. Power requirements are low and land requirements moderate.

Numerous variations on the basic principle of operation (i. e., the contact of influent particles with settling sludge) are commercially available. These variations include rim inflow with center outflow, various designs of the scraper mechanism, and various methods of supporting the scraper mechanism. Most of these variations are of minor importance with regard to solids separation efficiency, as measured by the concentration of suspended solids in the overflow and the corresponding underflow. The addition of chemicals such as alum, ferric chloride, lime, and synthetic polyelectrolytes as coagulant aids markedly improves solids separation efficiency. Such additions should be carried out in a separate mixing and flocculating unit preceding the clarifier.

The Degremont-Cottrell clarifier may be considered a major deviation from the conventional sludge-contact clarifiers. This unit employs a semi-batched mode of operation and achieves very-well-controlled hydraulic conditions. Although a somewhat greater separation efficiency is claimed for these units, chemicals are normally added as coagulant aids and the improved efficiency may to some degree be dependent on the use of the chemicals.

A reactor-thickener, unlike the conventional clarifier, has a separate, central slurry-contact zone. Coagulant aids are added in this zone, where a relatively heavy solids concentration is kept suspended by rapid mixing. High overflow rates are possible without increasing the suspended solids concentration in the overflow. The underflow concentration, however, tends to be somewhat low in comparison with that of conventional clarifiers.

Horizontal-Flow Sedimentation Tanks. These tanks are commonly rectangular in shape, with bottom scrapers for removing settled particles. In general, they are used for very dilute suspensions, such as for raw municipal wastewater, where solids contact cannot be achieved efficiently. For heavy suspensions, such as those expected from the scrubber operation, horizontal-flow sedimentation tanks would require much larger land areas than the sludge-contact clarifiers discussed above. Operating costs are relatively low.

Tube Settlers. These recently developed devices are based on the creation of laminar or near laminar flow in numerous inclined tubes where particles settle out at extremely high rates. The method holds a great potential for reducing space requirements for solids separation stages but is still not developed to the point where full-scale commercial applications should be considered without specific experimental data.

Vacuum Filters. Both drum type and disk type vacuum filters need to be considered. The disk type has a larger effective surface area and lower capital and operating costs than the drum type but requires more consistent and nonblinding slurries. Both types require relatively high concentrations of incoming slurry, preferably with several percent of solids. At lower concentrations, the required filter area becomes excessive. The solids content of the filter cake, for the standard type of vacuum filter, would be 60 to 70 percent with the type of solids produced in the scrubbing process. At regular intervals, normally once every three to six months, and as often as once a week if blinding occurs, the disk filter operation must be shut down for one to two hours for filter-cloth replacement. To avoid this frequent shutdown when dewatering slurries possessing a potential for filter blinding, the drum belt type of filter is used. With this filter, the filter cloth is washed with high-pressure sprays after discharging the filter cake and the cloth returns clean to the filtration cycle. Precoating filters are used for very fine or otherwise difficult materials, but impose high operating costs.

Centrifuges. Centrifuges are available that can concentrate scrubber effluent slurry to 70-percent solids or more. For economical operation, the influent should have 20 percent or more solids. While imposing somewhat higher capital and operating costs than a vacuum filter, a centrifuge will handle varying constituents, concentrations, and flow-rates somewhat easier. Abrasive materials may be handled by hard-metal coating of critical surfaces.

Flotation. Dissolved-air or froth flotation processes may achieve similar or better solids separation than a clarifier, particularly in cases where very small particle sizes are predominant. The efficiency of the process depends primarily on the electrochemical properties of the particle surfaces. Both purchasing and operating costs are higher than for a thickener, while space requirements are lower.

Other Methods. Several other types of solids/liquid separators, such as sand filters, pressure filters, vortex clarifiers, and strainers, are being employed in the process industries. These would be significantly more costly, however, than the methods described above, which in general take more efficient advantage of the fairly good settling and filtering properties expected of the scrubbing-process slurries.

Surface-Active Chemicals – Coagulants. The efficiency of any solids/liquid separation process is primarily a function of particle size and particle form. Large and dense particles are desired, while flaky or filamentous forms may cause operational problems. The rate of formation of larger particles from nuclei is related to the electrochemical properties of the particle surfaces (zeta potential), which in turn may be controlled and enhanced by the addition of chemicals such as alum, ferric chloride, and synthetic polyelectrolytes. Physical agglomeration to larger-sized particles can then further be improved by introducing shear forces (by mixing or pumping) that will bring the particles together and also break up filamentous forms. Thus, the use of such chemicals and methods is an attractive way of reducing the sizes of solids/liquid separation units. However, surface-active chemicals may also have an effect on the reactions related to SO_2 removal that are taking place in the scrubber. Whether the effect would be significant cannot be ascertained from theoretical considerations, but the possibility that adverse effects might arise would seem to preclude the design of a solid wastes handling system that relies on the effects of such chemicals.

9.2.2 Solids Disposal

The most attractive method of ultimate solids disposal is through reclamation and reuse. Direct reclamation of the original process reactants or production of salable by-products is at this time not economically feasible. However, the test data referred to earlier (Section 9.1.5) on material similar to dewatered slurry indicate that good cementation properties can be expected over a longer period of time. Thus, uses for the slurry may be found as soil stabilizing material in highway construction. Before such usage can become commercially feasible, however, much more study is required on the basic properties of the material, particularly with respect to the effect of long-term leaching of water-soluble constituents. For some time to come, disposal as nonreclaimable material will therefore remain the only alternative.

For plant sites on or near ocean frontage, the most economical method of disposal is likely to be direct disposal through an ocean outfall. The solids content of the wastes should in this case be below 30 percent, thus influencing the design considerations for the solids/liquid separator facility. Other parameters, peculiar to the site in question, but still of determining importance for facility design, are bottom topography, prevalent current systems, wave patterns, and the prevention of harmful effects to fish and other marine organisms.

Most power plants, including the experimental facility, will have to resort to disposal by some form of landfill operation. Here, the cementitious properties of the material would be particularly beneficial.

Transportation of solids from the plant site to the landfill site could be arranged in several ways. In recent years, pumping of heavy slurries over long distances has sometimes proven economical. For full-size facilities, this method of transportation should be investigated closely. For the experimental facility, hauling by truck or rail is more attractive. The solids should be dewatered as much as possible to reduce the volume to be hauled, preferably to 60 to 80 percent solids by weight.

Solids are probably most economically hauled on a normal five-day week with eight-hour days. This would require storage space for three days of operation, including one day's storage for operational flexibility.

Methods available for producing solids of a consistent and minimal moisture content include those reviewed in the previous section and, in addition, settling ponds or drying beds. Such facilities consist of crude ponds or ditches filled and drained in a batch operation. As the suspended solids settle, excess water evaporates from the surface or is drained off. When the solids capacity is reached for a particular pond or ditch, the dewatered material is moved elsewhere for landfill and the dewatering cycle is repeated. While very economical, such operations require large areas of land not normally available to power plants.

At the landfill site, solids may be dumped and distributed by conventional sanitary-fill and cover methods or by the use of scraper systems common to the mining industry. In either case, a careful arrangement of drainage ditches surrounding the disposal site is required to reduce the amount of surface runoff coming in direct contact with the solids. Even so, some amount of leachate will be produced as a result of continuing gravity settling, solidifying processes, and by incident precipitation. The quality of this leachate may in some instances have to be controlled by treatment to avoid objectionable effects on receiving waters.

9.3 RECOMMENDATIONS

The system to be designed for the experimental facility must ensure the reliability of solids-separation and scrubber process-water production for all modes of operation. To allow direct comparison of experimental data from the three scrubbers and maintain the capability to operate individual units alone, a separate systems train is required for each scrubber. For general reference with regard to the following recommendations, the basic systems train flowsheet is presented below.

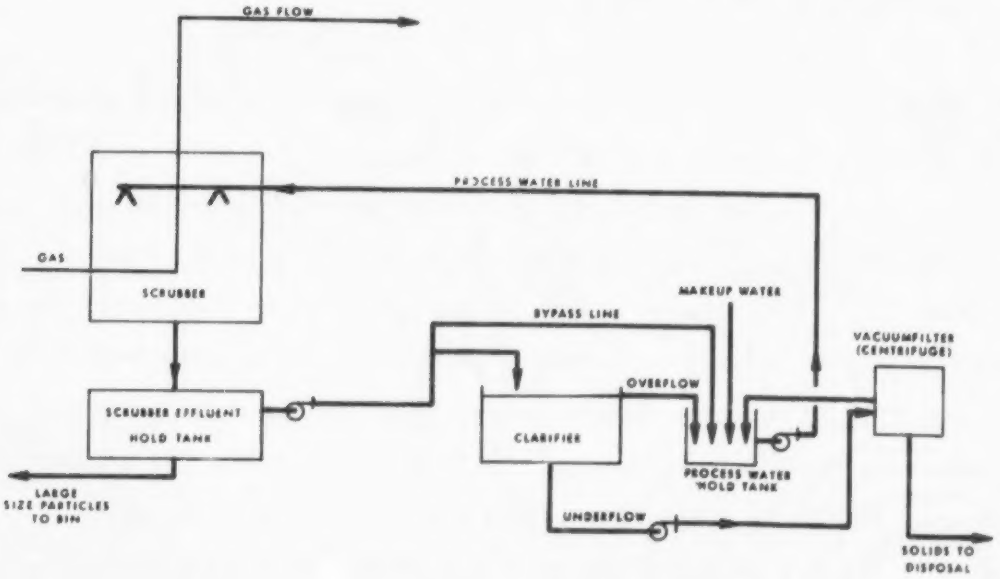

GAS FLOW
PROCESS WATER LINE
GAS
SCRUBBER
MAKEUP WATER
BYPASS LINE
VACUUMFILTER (CENTRIFUGE)
OVERFLOW
SCRUBBER EFFLUENT HOLD TANK
CLARIFIER
PROCESS WATER HOLD TANK
LARGE SIZE PARTICLES TO BIN
UNDERFLOW
SOLIDS TO DISPOSAL

Figure 9-1. Flowsheet, Basic Systems Train

9.3.1 Slurry Handling

When, as is expected to be the case with the scrubber slurries, reasonable separation can be achieved with 2-hour residence times, gravity methods of separation are significantly less expensive than the use of mechanical separators. Thus, the primary unit for the separation of slurry solids at the St. Clair plant should be based on gravity separation.

The type of unit recommended here is the conventional solids-contact clarifier with a heavy-duty rake or scraper mechanism supported by a center column, such as would be mandatory for the very large units conceivable for a full-scale installation. While experimental work with addition of coagulant aids is recommended, the design for the experimental facility should be based on no such addition. With a hydraulic loading of 0.75 gpm per square foot and a volumetric residence time of two hours at a flowrate of 2000 gpm, the dimensions of the clarifier tank would be 60 feet in diameter with a 12-foot side wall. In conjunction with a clarifier bypass line, a unit of this size would satisfy all requirements for concentrating suspended solids in the scrubber process-water stream.

The intermittent discharge of large-size particulate material from the scrubber walls discussed in Section 9.1 is a potential source of operational upsets. The Union Electric facility has had to shut down several times as a result of line plugging traced to discharges of large-size particles. For this reason, a unit for separating such material should be provided at the scrubber outlet. The unit recommended here is a circular, 15-foot diameter, 8-foot-high sedimentation tank in which the hydraulic conditions may be controlled by a variable-speed mixer. The mixer should be adjustable to achieve separation and removal of large-size particles without the removal of significant amounts of fines.

For the experimental facility, solids will be hauled to a landfill site by truck. This will require a secondary concentration or dewatering of the clarifier underflow. By vacuum filtration or centrifuging, a solids discharge of 70-percent solids by weight can be achieved. To ensure direct comparability of the scrubber operational data and flexibility of operation, three separate and identical units are suggested. The disk-type vacuum filter, if applicable, definitely would be the most economical dewatering unit. However, the lack of relevant data on the filtering properties of the slurry and the great range of modes of operation preclude the selection of disk filters as a basic dewatering unit. While a cloth-type, drum-vacuum filter and centrifuge would have about the same capital cost and operational performance, the cloth-type filter would have somewhat lower operational cost and also be capable of generating data needed to evaluate the applicability of a disk filter. Thus, three cloth-type vacuum filters incorporating a cloth-washing sequence are recommended for dewatering the clarifier underflow. For a backup unit, a centrifuge is recommended. In addition to providing operational flexibility, this arrangement will also be capable of developing comparative data on the performance of filters and centrifuges. Based on manufacturers' recommendations, the filter should be 6 feet in diameter with an 8-foot length of filter, and the centrifuge should be 24 inches in diameter with a 60-inch length. The units should be installed with piping and other facilities required for experimental application of chemical coagulant aids.

A hold tank is required for the scrubber process-water as it emerges as the clarifier overflow. This hold tank may be used to mix flow streams from the clarifier overflow, the clarifier bypass line, and the makeup water source. Under normal operation, it will also provide storage for the volume of process water carried above the static level in the clarifier. The size recommended is 15 feet in diameter by 10 feet high, with normal operation at the 5-foot level.

To ensure trouble-free operation of the test facility, the piping, tanks, pumps, and other exposed equipment should be designed to withstand relatively severe corrosion.

The requirements for treatment (such as softening and pH control) of effluent discharged to the environment during plant shutdown must be based on analytical data from operation of the test facility. It is, however, recommended that piping systems and a softening-chemical mixing and feeding facility be incorporated into the design. Such a facility can use the basic elements of the primary solids/liquid separation facility. The process-water hold tank may be used as a chemical feed and flash mixing tank and the scrubber-effluent holding tank as a flocculation tank, with the clarifier removing the precipitated solids. The softened water can be discharged directly to the river or may be discharged to the plant ash pond. In case it is necessary to drain water from the system at an extremely rapid rate, the water would be passed through the process-water hold tank, chemicals added, and the water discharged to the ash pond.

After chemical treatment and settling in the clarifier or the plant ash pond, the liquid will have a hardness on the order of 500 milligrams per liter and a suspended solids content of 200 to 300 milligrams per liter. The pH may be somewhat on the alkaline side, but not to an objectionable extent. The water supply standards set by the Michigan Water Resources Commission, cited in Appendix C, are expected to be satisfied by this treatment.

9.3.2 Solids Disposal

The recommended method for solids disposal is based on hauling and disposal by 26-ton trucks of the type presently used to haul fly ash from the plant to a landfill site. At maximum alkali injection rate, the total output of solids from all three scrubbers will be about 25 tons per hour, at which rate it is assumed that the filter cake will contain 70 percent solids by weight. With continuous scrubber operation at that level and trucking scheduled for eight hours per day and five days per week, four truckloads per hour or 32 truckloads per day are required.

To allow truck scheduling as indicated above, a storage area must be provided. The most economical and practical method for the experimental facility is storage in an open bin. The angle of repose must be ascertained by experiment to create a basis for design of the storage pile. Loading from the pile onto trucks is done by the use of a front-end loader with a capacity of about three cubic yards. For transport from the filters (and centrifuge) to the storage pile, conveyor belts are recommended.

The environmental-pollution potential of leachate from the solid wastes disposal pit depends primarily on the amounts of incident precipitation and surface runoff contacting the disposed slurries. These flows may be reduced greatly by a suitable arrangement of drainage ditches and holding structures surrounding the disposal site. Although it is difficult to predict, from theoretical considerations, the actual amount of dissolved and suspended solids that will be carried away in the leachate, it appears that the total amount from the experimental facility will be too small to affect receiving surface-waters significantly. The amount of leachate entering groundwater basins would be even smaller.

Section 10

FLUE GAS REHEAT

The purpose of flue gas reheat is to prevent vapor-plume formation and to protect the induced-draft fans from deposits. The main objectives for considering three reheat systems are to provide an analysis of the relative merits and generate cost estimates for each design.

10.1 METHODS CONSIDERED

Several methods of reheating the exhaust gases were considered. The following three were tentatively selected for the test facility:

- Reheat by direct combustion of natural gas
- Reheat by steam heater
- Regenerative reheat by means of a closed hot-water cycle

Direct gas-combustion reheat utilizes natural gas available in the gas header of the plant and introduces the gas through multiple burners directly into the flue-gas stream after the flue gas leaves the scrubber. Combustion air is provided by a small blower adjacent to the ductwork. The arrangement of the burners is such as to promote thorough mixing and even heating of the flue gas stream. The rate of reheat can be controlled by the amount of gas fired, which in turn can be adjusted by the test personnel through the gas control valve.

In the second alternative, a steam reheater receives intermediate-pressure steam (assumed at 85 psig). The reheater is a finned-tube heat exchanger accommodated in the ductwork as close to the scrubber-exhaust flange as possible. It is anticipated that mist and particulate carry-over from the scrubber would be deposited between the exchanger fins, tending to clog it. For periodic cleaning, water-spray spargers must be provided above the reheater. This arrangement will avoid the washwater's being carried on into the induced-draft fan. Condensate from the heater is returned through a standard trap assembly, condensate tank, and pumping unit to the plant condensate system.

The third alternative, the regenerative reheater, consists of two heat exchangers: one, the extractor, precedes the scrubber and removes part of the sensible heat from the flue gas; the other, the reheater proper, reintroduces this heat into the flue gas after it leaves the scrubber. Both heat exchangers are of the finned-tube type and are parts of a closed hot-water system. The hot water is pumped through the extractor and the reheater, in that order. An expansion and makeup tank will keep the hot-water circuit filled and under controlled pressure. Since the extractor operates in a high dust-load area, its fins are prone to be blocked by dust deposits. Compressed-air-operated soot-blowers will be used for periodic cleaning. The finned tube reheater is cleaned the same as is the steam reheater described above.

Justification of the reheater selections can be summarized as follows:

- The direct-fired natural gas reheater is the simplest system for the service. It is not prone to clogging and affords accurate control over a broad operating range. It is the most suitable for a test facility where the objective is to determine the minimum amount of heat needed for reheating. Being the most flexible system, it is the one that should be taken through the reheater test program described in Section 14 of this report.

- The steam reheater was selected as an alternative because steam is a heat source available in every power plant. Its advantage is accurate temperature control.
- The regenerative reheater is the most efficient system thermodynamically. It does not require extra heat input but uses heat extracted from the hot gases to reheat the cold exit gases from the scrubber. (This heat extracted from the hot gases would be wasted in the scrubber anyway and would, in fact, increase the evaporative losses in the scrubber.) The regenerative system would very probably find application in large power units if reheat proves to be a continuous requirement. Comparative drawbacks of the regenerative system are its larger heat-transfer-requirement, its higher pressure drop, and its demand for a highly effective mist eliminator. These tend to make the initial cost of the regeneration reheater system higher than that for the other two systems – a disadvantage that must be compensated for by savings through thermodynamic efficiency.

Other methods for flue gas reheat were also considered. Oil burners, for example, could be used instead of gas burners where oil is more economical. The oil could be residual or of diesel quality. In the case of the former, oil heaters would have to be provided to maintain the low viscosity needed for atomizing. The arrangement of the oil burners could be similar to that of the gas-fired reheaters. Because of the low excess air in the stack gases, a separate air supply fan would be required, as is recommended for the gas-fired reheater.

Regenerative-type heat exchange can be obtained other than through a closed water-cycle. A Ljungstrom-type rotary heat exchanger as used in the boiler air heater could be applied as a regenerative flue-gas reheater. This type of equipment might prove more economical in the long run than intermediate fluid systems Its application for the experimental equipment, however, was not recommended for the following reasons:

- The narrow passages of the Ljungstrom heat exchanger are prone to clogging in the moist atmosphere of the scrubber exhaust gas.
- Heavy structural steel support and more involved ductwork would have consumed any possible savings.
- The unavoidable leakage in the Ljungstrom system would interfere with accurate measurements and material-balance calculations.
- A tubular-type air heater could also be used for regenerative reheating. This type of heat exchanger requires a very involved ductwork that would have restricted the accessibility to the scrubber. For this reason, it was not selected for the test facility.

Electric heaters, too, could be used to reheat the flue gas. The simplicity of this method has a special appeal, particularly for experimental equipment. However, the large amount of heat demand and the comparatively high cost of electricity as a heat source would advise against such an application. Electric heaters would require a power input of between 2000 and 3000 kilowatts for each scrubber system.

10.2 MOISTURE CARRYOVER

The efficiency of the mist eliminators in the scrubbers has a profound effect on reheater economics. This is because sensible heat cannot be introduced until the moisture carried in the flue gas is evaporated. As an example, 200 scfm of 1000-Btu-per-scfm natural gas would be required to raise the temperature of saturated but non-moisture-carrying flue gas from 125 F to 185 F. If the mist eliminators passed just 0.5 percent by weight of non-evaporated moisture, another 25 scfm of natural gas would be required to evaporate the carryover mist before the heat applied would be sensible. (Measuring the fuel required for reheat is thus an accurate way to determine the efficiency of mist eliminators.)

The limited heat-transfer capability of regenerative reheaters makes them especially vulnerable to mist carryover. Where they are used, high mist-eliminator efficiencies must be achieved.

Assuming that mist-eliminator efficiency is not compensated for by extra reheating, mist carryover increases the likelihood of a plume forming at the stack because the lower-temperature exiting gas has a lower buoyancy and diffusion rate.

10.3 HEAT EXCHANGERS

For the regenerative extractor and reheater and the steam-heated reheater, finned-tube exchangers of carbon steel are planned. More expensive material cannot be justified for the relatively short duration of the experiments.

All three exchangers have a total heat transfer surface of about 7000 square feet each: this is the finned surface on the flue gas side. The final exchanger design will be established during Phase II, at which time the air pressure drop will also be determined.

10.4 RECOMMENDATIONS

With three parallel and independent scrubber systems, it is logical to apply different types of reheat systems to each of them. This permits extending the experiment to observe the behavior of various reheater systems.

The scrubbers should be mated with their respective reheater systems to minimize as far as possible the differences in pressure drop through the parallel flue-gas trains. Thus, the scrubber with the highest pressure drop should be paired with the reheater with the lowest pressure drop and vice versa. Accordingly, the venturi-type scrubber should be equipped with the gas reheater and the flooded-bed scrubber should be paired with the regenerative-type reheater.

Section 11

PROCESS DESIGN

11.1 DESIGN CRITERIA

The scrubbing processes have been designed for considerable flexibility in operation of the scrubber modules. This is to enable investigation of various modes of scrubber operation and to provide a wide range of system operating conditions and scrubber designs. Layout of equipment makes the best use of the site available at the St. Clair plant consistent with easy operation of the test facility. Prime emphasis has been placed on obtaining as much accurate information as possible from the test program. Consideration has been given to uninterrupted operation of the steam generator and to the safety of operating personnel.

Data supplied by Detroit Edison on coal composition, ash composition, high heating value of the coal, and steam generator heat rate are listed in Table 11-1. From these data and the assumptions listed in Table 11-2, the flue gas volume and composition were calculated. Typical flue gas composition is shown in Table 11-3.

Coal composition data supplied by Detroit Edison indicate that the sulfur content varies from 2.5 to 4.5 percent, with an average value of 3.3 percent. Equipment design was based on handling the flue gas and particulates that would be injected when the highest-sulfur coal was being used. The highest stoichiometric additive feed rate to be tested was taken as 250 percent.

Table 11-1

DATA SUPPLIED BY DETROIT EDISON COMPANY

Unit Operating Data	Heat rate	9, 240 Btu/kwh
	High heating value of coal	11, 700 Btu/lb
	Maximum generator output	~160 Mw
	Excess air @ full load	17%
	Excess air @ 62% load	23%
	Excess air @ 31% load	45%
Coal Composition	Carbon	71. 1%
	Nitrogen (N_2)	1. 3%
	Oxygen (O_2)	7. 3%
	Hydrogen (H_2)	5. 0%
	Sulfur	2. 5-4. 5% typical 3. 3%
	Ash	11-16% typical 12%
Ash Composition	SiO_2	40-55%
	Al_2O_3	15-25%
	Fe_2O_3	15-18%
	TiO_2	0. 8-1. 0%
	CaO	2-8%
	MgO	0. 8-1. 5%
	Na_2O	0. 6-1. 5%
	K_2O	1-2. 5%
	P_2O_2	0. 3%

Table 11-2

ASSUMPTIONS USED IN CALCULATING FLUE-GAS COMPOSITION

CO/CO_2 ratio in the flue gas	0.0
Humidity of inlet air	0.012 lb/lb
Combustible material in the ash	0.0
Percent conversion of SO_2 to SO_3	0.5%

Table 11-3

TYPICAL CALCULATED FLUE-GAS COMPOSITION*

(mole percent)

SO_2	0.213
CO_2	14.40
N_2	73.2+
A	0.87
O_2	2.85
CO	0.0
H_2O	8.39
SO_3	0.001

*Steam generator operating at full load with typical coal composition

Calculations show that at full load the steam generator would produce 550,000 cfm of flue gas measured at 275 F and 14.315 psia. Based on the assumption that each scrubber should handle approximately one sixth of the total flue gas, the scrubbers were each sized to accommodate 100,000 cfm at inlet conditions.

The material balances shown in Tables 11-4, 11-5, and 11-6 list the flows in all process lines for various modes of operation. The numbers in diamonds, ◇n, at the heads of the table columns correspond to the same symbols in Figures 3-5, 3-6, and 3-7.

Table 11-4 lists the mass flow of materials for injection of 30-percent excess limestone, assumed to be composed of 95-percent $CaCO_3$ and 5-percent inerts. Table 11-5 lists the mass flows for injection of 150-percent excess limestone of the same composition. Table 11-6 lists the mass flows for injection of 150-percent excess dolomite composed of 48-percent $CaCO_3$, 48-percent $MgCO_3$, and 4-percent inerts. These conditions were chosen as representative of normal operating conditions and highest solids-loadings that will be encountered.

The assumptions made in calculating the material balances are as follows:

1. With 130 percent of stoichiometric injection of limestone or dolomite, 20 percent of the SO_2 is removed in the boiler, forming only $CaSO_4$.
2. All the dolomite or limestone is calcined in the boiler.
3. Eighty-five percent of the ash in the coal leaves the boiler as flyash; 15 percent leaves as bottom ash.
4. All of the injected additive leaves the boiler in the flue gas.
5. The SO_2-removal efficiency of the process is 90 percent with an injection rate of 130 percent of stoichiometric, and 95 percent with an injection rate of 250 percent of stoichiometric.

Table 11-4

MATERIAL BALANCE SUMMARY
NORMAL OPERATION – 30 PERCENT EXCESS LIMESTONE

Compound	FLOW: POUNDS/MINUTE											
	⟨1⟩	⟨2⟩	⟨3⟩	⟨4⟩	⟨5⟩	⟨6⟩	⟨7⟩	⟨8⟩	⟨9⟩	⟨10⟩	⟨11⟩	⟨12⟩
SO_2	21.34		Same as Column 2	Does Not Apply To This Mode Of Operation							2.68	Same as Column 11
CO_2	1124.75										1117.76	
N_2	3564.12										3564.12	
A	60.40										60.40	
O_2	158.40										154.85	
CO	0.00										0.00	
H_2O	262.40	8141.0			7890.0	205.2	247.0	46.2	251.30	8342.9	453.60	
SO_3	0.00										0.00	
CaO(s)	25.60										0.25	
$CaSO_4$(s)	11.34										0.11	
MgO(s)												
Flyash	36.52	36.15						36.15	36.15		0.36	
Inerts	1.70	1.68						1.68	1.68		0.02	
$CaSO_3 \cdot 2H_2O$(s)		21.54						21.54	21.54			
$CaSO_4 \cdot 2H_2O$(s)		37.56						37.55	37.55			
$MgSO_3 \cdot 7H_2O$(s)												
$CaCO_3$(s)		12.48						12.48	12.48			
$Mg(OH)_2$(s)												
Ca^{++}		5.0			4.84	0.13		0.03	0.16	4.97		
Mg^{++}												
$SO_4^{=}$		12.1			11.73	0.30		0.07	0.37	12.03		
$SO_3^{=}$		0.11			0.107	0.0025		0.0005	0.003	0.11		
Gas Flow	5191.41										5353.41	
Liquid Flow		8152.21			7906.68	205.63	247.0	46.3	251.83	8360.01		
Solids Flow	75.16	109.50						109.5	109.5		0.74	
Total Flow	5267.57	8261.41			7906.68	205.63	247.0	155.8	361.33	8360.01	5354.15	
Temp. °F	275	125			125	125	60	125	125	123	125	275

Table 11-5

MATERIAL BALANCE SUMMARY
MAXIMUM SULFUR CONTENT IN COAL – 150 PERCENT EXCESS LIMESTONE

Compound	FLOW: POUNDS/MINUTE											
	1	2	3	4	5	6	7	8	9	10	11	12
SO_2	23.62		Same as Column 2	Does Not Apply to This Mode of Operation							1.81	Same as Column 11
CO_2	1119.81										1082.72	
N_2	3545.36										3545.36	
A	60.40										60.4	
O_2	157.60										146.25	
CO	0.00										0.00	
H_2O	289.56	8132.1			7577.1	458.6	312.33	101.54	569.8	8342.9	480.80	
SO_3	0.00										0.00	
CaO(s)	69.79										0.69	
$CaSO_4$(s)	27.03										0.27	
MgO(s)												
Flyash	57.86	57.28						57.28	57.28		0.57	
Inerts	4.38	4.33						4.33	4.33		0.04	
$CaSO_3 \cdot 2H_2O$		26.58						26.58	26.58			
$CaSO_4 \cdot 2H_2O$		64.43						64.58	64.58			
$MgSO_3 \cdot 7H_2O$												
$CaCO_3$		84.30						84.30	84.30			
$Mg(OH)_2$												
Ca^{++}		4.95			4.61	0.28		0.06	.345	4.89		
Mg^{++}												
$SO_4^=$		12.13			11.29	0.69		0.15	.845	11.98		
$SO_3^=$		0.107			0.104	0.002		0.001	.003	0.106		
Gas Flow	5196.35											
Liquid Flow		8161.89			7593.10	459.57	312.33	101.75	570.99	8359.88	5317.34	
Solids Flow	159.06	246.92						246.92	246.92		1.57	
Total Flow	5355.41	8401.01			7593.10	459.57	312.33	348.67	817.91		3518.91	
Temp. °F	275	125			125	125		125	125	123	125	275

Table 11-6

MATERIAL BALANCE SUMMARY
MAXIMUM SULFUR CONTENT IN COAL – 150 PERCENT EXCESS DOLOMITE

Compound	FLOW: POUNDS/MINUTE											
	1	2	3	4	5	6	7	8	9	10	11	12
SO_2	23.62		Same as Column 2	Does Not Apply to This Mode of Operation							1.81	Same as Column 11
CO_2	1119.81										1105.95	
N_2	3545.36										3545.36	
A	60.40										60.40	
O_2	157.60										149.90	
CO	0.00										0.00	
H_2O	289.26	8125.9			7629.14	405.6	308.12	91.16	496.76	8342.9	489.80	
SO_3	0.00										0.0	
CaO(s)	25.42										0.25	
$CaSO_4$(s)	27.03										0.27	
MgO(s)	31.32										0.31	
Flyash	57.86	57.28						57.28	57.28		0.58	
Inerts	5.40	5.35						5.35	5.35		0.05	
$CaSO_3 \cdot 2H_2O$		21.26						21.63	21.63			
$CaSO_4 \cdot 2H_2O$		57.63						57.63	57.63			
$MgSO_3 \cdot 7H_2O$		9.95						9.95	9.95			
$CaCO_3$		24.75						24.75	24.75			
$Mg(OH)_2$		38.68						38.68	38.68			
Ca^{++}		4.95			4.41	0.49		0.055	0.54	4.90		
Mg^{++}		32.54			30.56	1.62		0.36	1.98	35.18		
$SO_4^{=}$		12.13			10.80	1.20		0.135	1.33	12.0		
$SO_3^{=}$		0.109			0.102	0.006		0.0001	0.0007	0.108		
Gas Flow	5196.35										5353.22	
Liquid Flow		8176.62			7675.01	408.91	308.12	91.70	498.83	8395.08		
Solids Flow	147.03	214.99						214.99	214.99		1.46	
Total Flow	5343.38	8390.61			7675.01	408.91	308.12	306.69	513.82	8395.08	5354.68	
Temp. °F	275	125			125	125	60	125	125	123		275

6. Particulate removal efficiency is 99 percent for all scrubbers.
7. Fifty percent of the SO_2 removed in the scrubber leaves the process as precipitated sulfite; the other fifty percent leaves as precipitated sulfate.
8. Excess calcium leaves the scrubber as $CaCO_3$; excess magnesium leaves as $Mg(OH)_2$.
9. The solubility of $CaSO_4$, $CaSO_3$, $MgSO_3$, and $MgSO_4$ could not be determined for the process conditions encountered. The estimated solubility of these compounds was based on the best literature data. These values are presented in Appendix C.

Criteria used for design of the slurry handling and solids disposal system are summarized as follows:

1. Suspended and dissolved solids concentrations as shown in Table 11-7
2. Clarifier: overflow rate 0.75 gpm per square foot, residence time 2 hours, design flow rate 2000 gpm
3. Scrubber effluent hold tank: overflow rate 11 gpm per square foot, residence time 4 minutes, design flow rate 2000 gpm
4. Process water hold tank: clarifier overflow volume at shutdown 470 cubic feet, initial scrubber rinse water at shutdown 300 cubic feet
5. Filter: influent flow rate 70 gpm at 30 percent solids by weight, cloth load 75 lb per square foot per hour
6. Centrifuge: influent flow rate 70 gpm at 30 percent solids by weight
7. Filter or centrifuge solids conveyor: solids flowrate 10 tons per hour at 60 percent solids and 80 pounds per cubic foot bulk density
8. Storage-pile transport conveyor: 30 tons per hour at 60 percent solids and 80 pounds per cubic foot bulk density
9. Materials of construction: scrubber units, 316 stainless steel; clarifier tank, ASTM-A-36 welded steel, rubber lined; hold tanks, rubber-lined, low-carbon steel; pipelines, natural-rubber-lined carbon steel; butterfly control valves and pump, Alloy 20 or equivalent

Table 11 - 7

SUSPENDED AND DISSOLVED SOLIDS IN SCRUBBER EFFLUENT

(milligrams per liter)

Solids Content		Normal Operations, 30% Excess Limestone Injection	Maximum Sulfur Content, 150% Excess Limestone Injection	Maximum Sulfur Content, 150% Excess Dolomite Injection
Suspended Solids	Flyash	4,410	6,950	6,920
	Inerts from Injection Material	210	520	650
	$CaSO_3 \cdot 2H_2O$	2,630	3,220	2,570
	$CaSO_4 \cdot 2H_2O$	4,580	7,800	6,970
	$MgSO_3 \cdot 7H_2O$	-	-	1,200
	$CaCO_3$	1,520	10,210	2,990
	$Mg(OH)_2$	-	-	4,670
	Total	13,350	28,700	25,970
Dissolved Solids	Ca^{++}	610	600	600
	Mg^{++}	-	-	3,900
	$SO_4^{=}$	1,480	1,470	1,470
	$SO_3^{=}$	10	10	10
	Total	2,100	2,080	5,980
Total All Solids		15,450	30,780	31,950

10. Insulation required for all minor pipelines, not required for clarifier-feed and scrubber-return pipelines
11. Piping sized for minimum flow rate of 2 feet per second at minimum anticipated flow ratio on all slurry lines

Section 12

INSTRUMENTS AND CONTROLS

12.1 ADDITIVE HANDLING

12.1.1 Data Accumulation

No specific instrumentation is foreseen for the additive-handling conveyor system. The amount of additive received will be registered at the gate when trucks pass through. The quantity of additive stored will be determined by visual inspection only.

The following measurements are provided for the additive feeding system:

- Quantity of Additive Injected

  The gravimetric feeder of the pulverizer will permit monitoring the limestone feed rate within ± 1.0 percent accuracy.

- Particle Size Distribution

  A sampling opening will be cut into one of the pulverized-coal-burner feed pipes. Samples will be taken at certain intervals and subjected to standard sieve analysis. With mill recirculation adjustment, the fineness of the product can be modified.

- Mill Temperature

  Existing instrumentation will monitor mill temperature.

- Moisture Introduced

  The intermittent sampling contemplated for size distribution measurement will also be used to determine moisture content of the additive and carrier gas injected into the furnace.

12.1.2 Controls

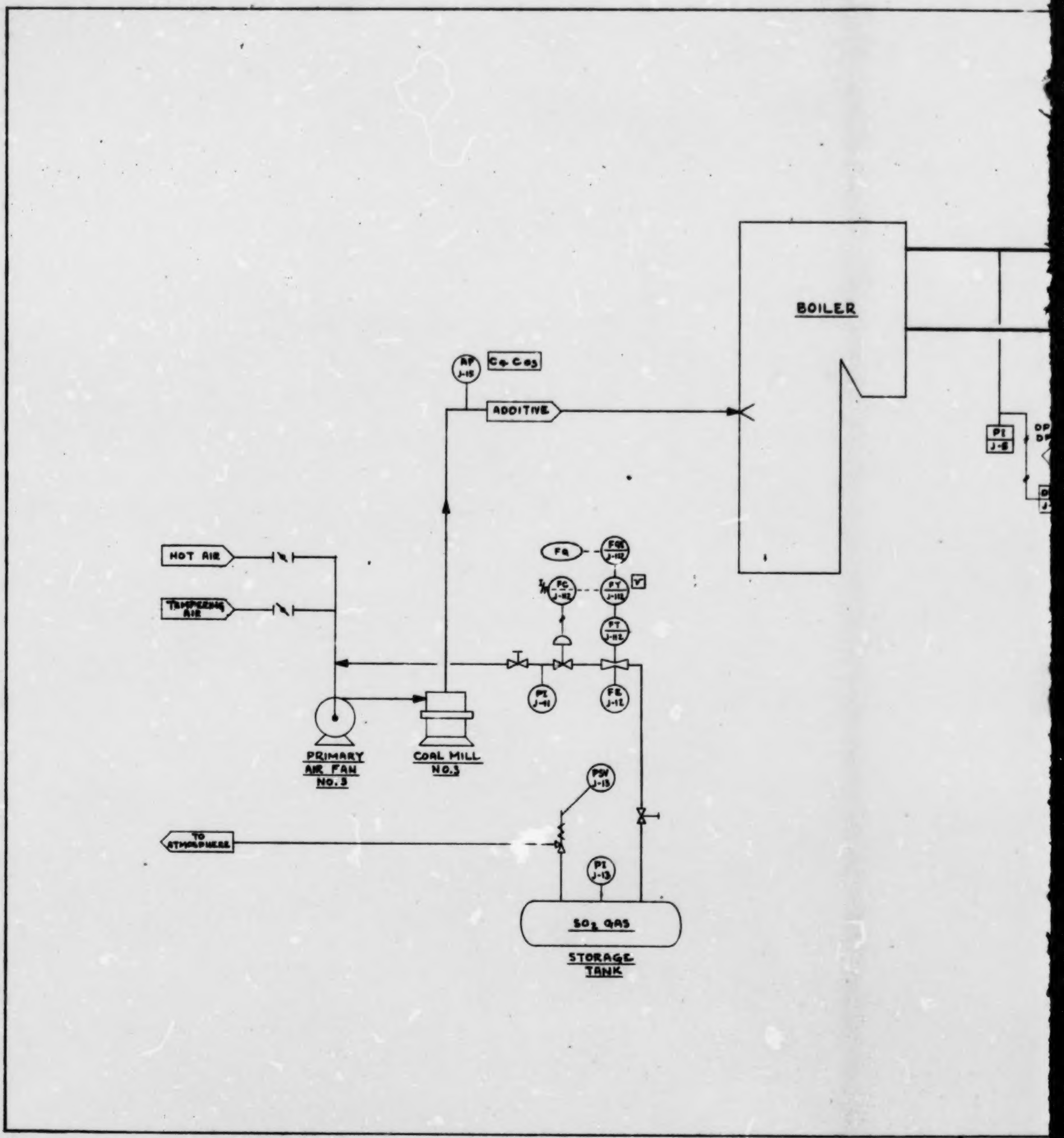
In order to prevent additive pileup in the crusher house, which could easily interfere with normal coal-handling operation, the Redler drive will be electrically interlocked with the conveyor drives of belts 1 and 3. In case of malfunction or inadvertent stoppage of either of the two conveyor belts, the Redler drive will stop. The interlock will not permit restart until both conveyors are running.

The pulverizer feed rate and primary air flow are normally controlled by the combustion control system of the boiler. For the duration of the limestone grinding service, mill 3 will be separated from the automatic control and placed on remote manual control from the boiler panel. The feeding rate and the rate of transport air introduction will be set by the boiler operator and adjusted by him upon request from the test personnel.

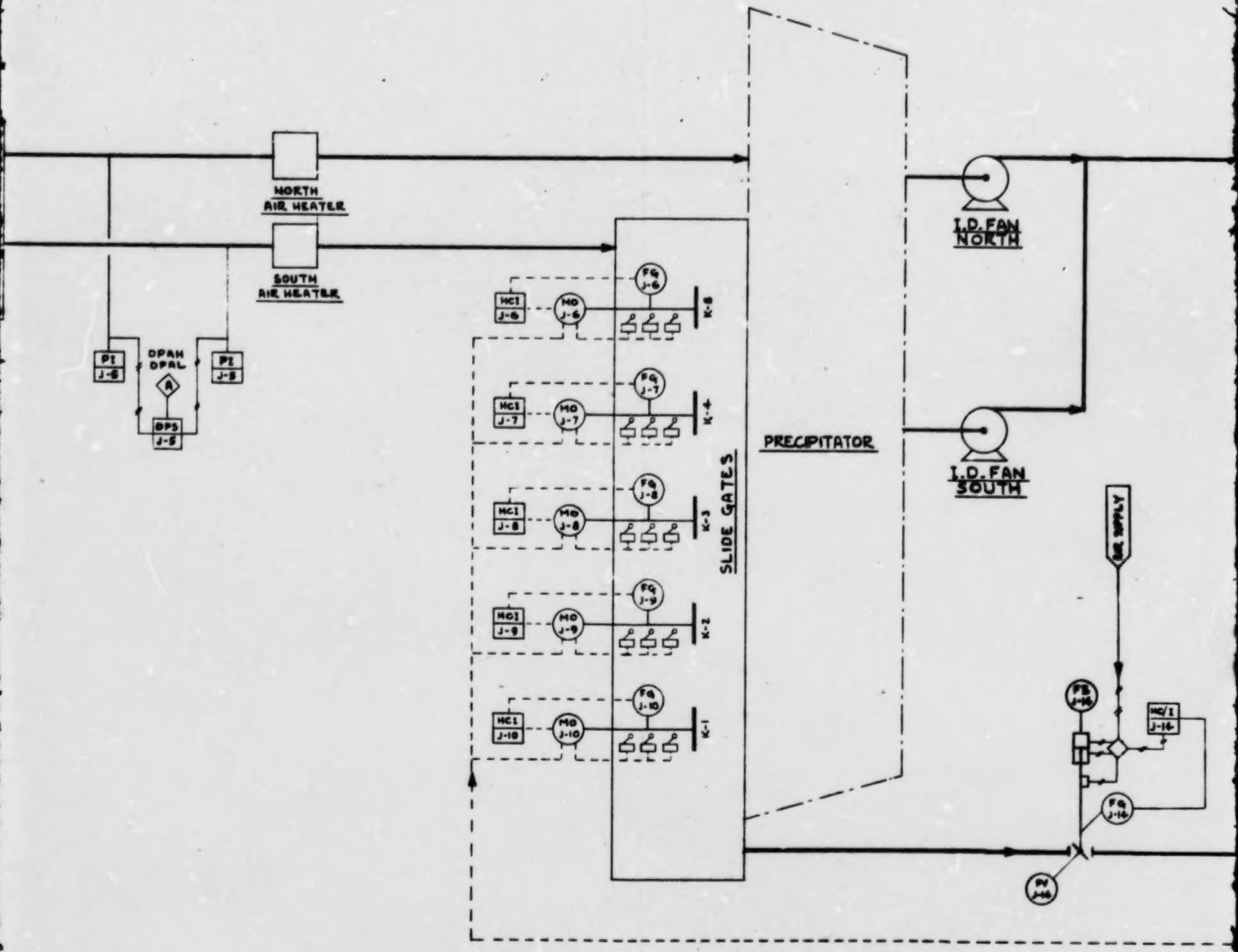
12.2 STEAM GENERATORS AND FLUE GAS HANDLING

12.2.1 Control Criteria and Requirements

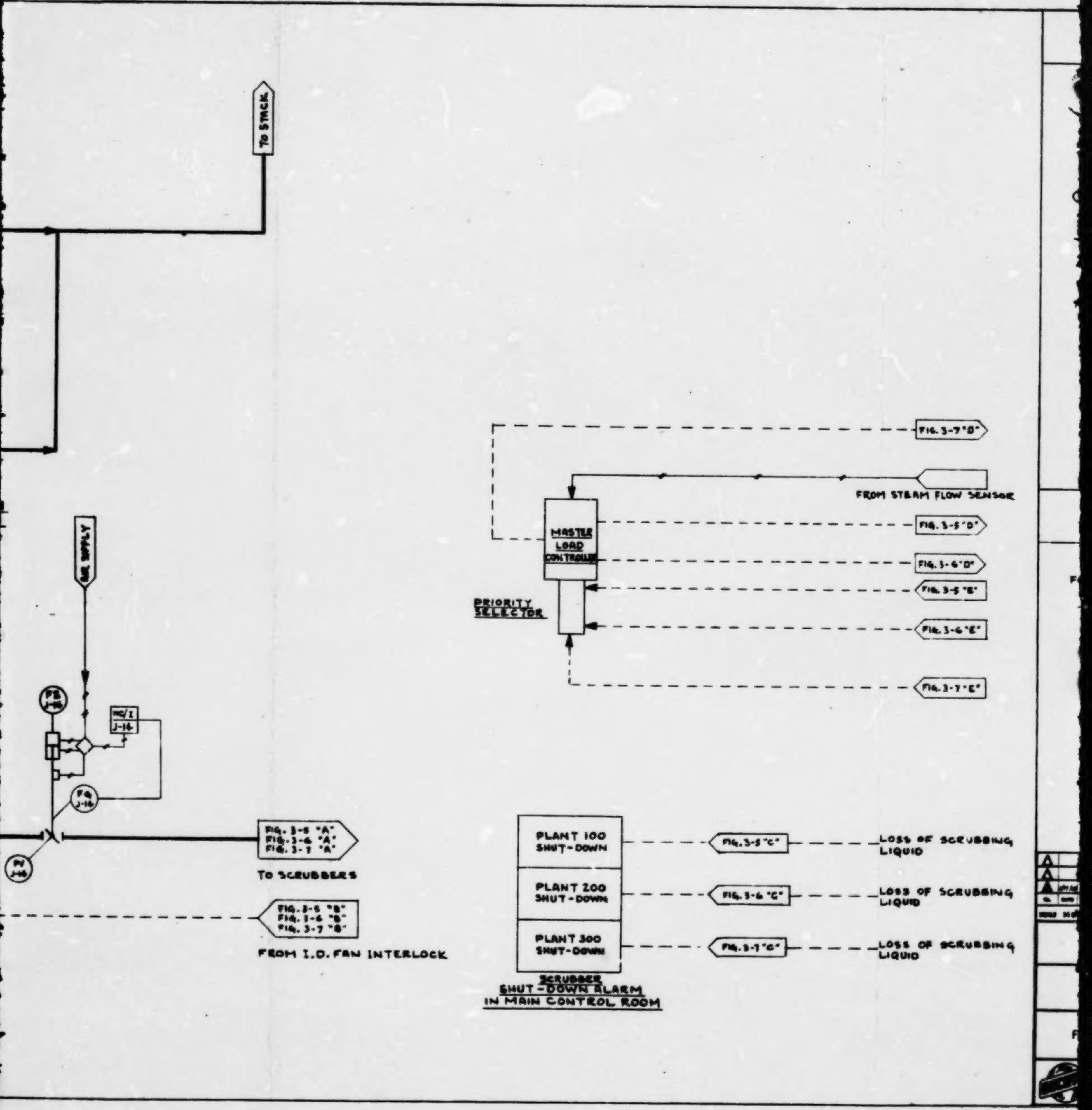
The criteria of design for the control system, as shown in Figure 12-1, are based upon system reliability, ease of operation, and the freedom of boiler no. 1 from the effects of disturbance occurring within the experimental project. Facilities are included for quick disengagement from the project and restoration of the existing mode of operation, should the necessity arise. All control functions that directly affect boiler operation (i.e., flue gas flow control, limestone injection, boiler pressure balance, and induced draft fans) are under the supervision and control of the boiler 1 control room operator. All the necessary indicators and controllers required for these control functions are installed on a separate control panel in the boiler 1 control room.


BOILER
AP J-15
Ca CO3
ADDITIVE
PI J-6
DP
HOT AIR
TEMPERING AIR
FQ
FQR J-112
FC J-112
FY J-112
FT J-112
PI J-11
FE J-12
PRIMARY AIR FAN NO. 3
COAL MILL NO. 3
PSV J-13
TO ATMOSPHERE
PI J-13
SO2 GAS
STORAGE TANK

A


NORTH AIR HEATER
SOUTH AIR HEATER
PI J-6
DPAH DPAL
A
DPS J-5
PI J-5
HCI J-6
MO J-6
FQ J-6
K-5
HCI J-7
MO J-7
FQ J-7
K-4
HCI J-8
MO J-8
FQ J-8
K-3
HCI J-9
MO J-9
FQ J-9
K-2
HCI J-10
MO J-10
FQ J-10
K-1
SLIDE GATES
PRECIPITATOR
I.D. FAN NORTH
I.D. FAN SOUTH
AIR SUPPLY
PB J-16
HC/I J-16
FQ J-16
PV J-16

B


TO STACK
AIR SUPPLY
PS J-16
HC/I J-16
FQ J-16
PV J-16
FIG. 3-5 "A"
FIG. 3-6 "A"
FIG. 3-7 "A"
TO SCRUBBERS
FIG. 3-5 "B"
FIG. 3-6 "B"
FIG. 3-7 "B"
FROM I.D. FAN INTERLOCK
FIG. 3-7 "D"
FROM STEAM FLOW SENSOR
FIG. 3-5 "D"
MASTER LOAD CONTROLLER
FIG. 3-6 "D"
FIG. 3-5 "E"
PRIORITY SELECTOR
FIG. 3-6 "E"
FIG. 3-7 "E"
PLANT 100 SHUT-DOWN
FIG. 3-5 "C"
LOSS OF SCRUBBING LIQUID
PLANT 200 SHUT-DOWN
FIG. 3-6 "C"
LOSS OF SCRUBBING LIQUID
PLANT 300 SHUT-DOWN
FIG. 3-7 "C"
LOSS OF SCRUBBING LIQUID
SCRUBBER SHUT-DOWN ALARM IN MAIN CONTROL ROOM

C

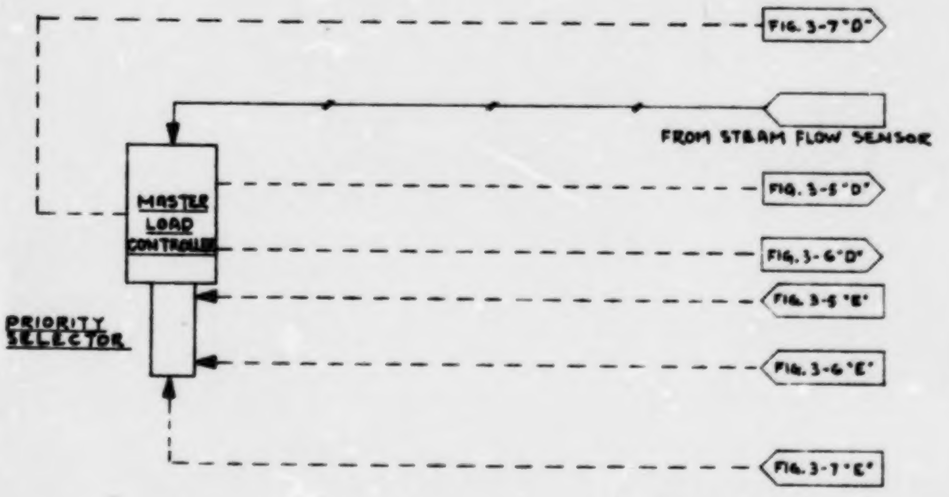
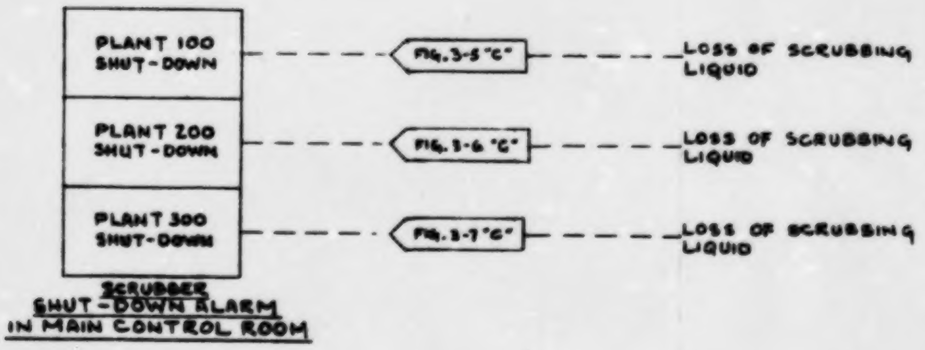


FIG. 3-7 "D"
FROM STEAM FLOW SENSOR
MASTER LOAD CONTROLLER
FIG. 3-5 "D"
FIG. 3-6 "D"
FIG. 3-5 "E"
PRIORITY SELECTOR
FIG. 3-6 "E"
FIG. 3-7 "E"


PLANT 100 SHUT-DOWN
FIG. 3-5 "C"
LOSS OF SCRUBBING LIQUID
PLANT 200 SHUT-DOWN
FIG. 3-6 "C"
LOSS OF SCRUBBING LIQUID
PLANT 300 SHUT-DOWN
FIG. 3-7 "C"
LOSS OF SCRUBBING LIQUID
SCRUBBER SHUT-DOWN ALARM IN MAIN CONTROL ROOM

SYMBOLS & ABBREVIATIONS

○ LOCAL MOUNTED DEVICE

⊟ DEVICE LOCATED IN BOILER CONTROL ROOM

⬭ DATA ACQUISTION INPUT

⊿ GATE POSITIONING SWITCH

○ DEVICE LOCATED IN TEST FACILITY CONTROL CENTER

NOTES

FOR GENERAL NOTES, SEE FIGURE 3-5

△								
△								
▲	[illegible]	ISSUED FOR REPORT				[illegible]	[illegible]	
		REVISIONS						

SCALE NONE | | J. HING

BECHTEL CORPORATION
SAN FRANCISCO

N. A. P. C. A.
ALKALI SCRUBBING TEST FACILITY
DETROIT EDISON ST. CLAIR PLANT-MICHIGAN

FLUE GAS INSTRUMENTATION & CONTROL DIAGRAM

JOB No.	DRAWING No.	REV.
6955	FIGURE 12-1	0

D

System design and operation are based upon maintaining precipitator temperatures above dew point, balanced gas flow within the boiler, flue-gas flow equivalent to boiler requirements, and minimization of the effects upon boiler operation of parameter changes or upsets within the experimental project.

During normal operation or prearranged changes in operation, gas flow variations through the test facility are either slow cycling or predetermined. Balanced gas flow within the boiler is maintained by manual positioning of the slide gates by the boiler room operator.

Upsets within the test facility, such as sudden scrubber clogging, unintentional damper closing, or induced-draft fan stoppage, will automatically position the slide gates to restore gas flow balance.

Any such changes in flue-gas flow rate through the test facility will be detected by the furnace draft sensors. The furnace draft controller will then make the necessary changes to the loading on the existing north and south induced-draft fans to maintain boiler steam load.

To maintain the temperature of the south precipitator above dew point, both the existing north and south induced-draft fans operate in parallel at reduced load, thereby maintaining gas flow through both sides of the precipitator. Splitting of the north flue-gas stream is accomplished by north to south cross-flow within the precipitator. During operation of the test facility, the total boiler flue-gas output is split evenly between the two existing induced-draft fans and the test facility. To maintain balanced gas flow within the boiler, whenever the test facility is operating at less than its allotted 50 percent, slide gates at the entrance of the precipitator are positioned to permit bypassing the excess flue gas to the existing induced-draft fans.

Conversely, if the boiler load should be reduced to less than full load, and the 50 percent share of the available flue gas to the test facility drops to less than the required amount, the test facility will automatically cut back its operations to a level consistent with the flue gas available. At the discretion of the test facility operator, any experiments in progress may be either terminated or continue at reduced levels.

The original furnace-gas-flow and pressure-balance control scheme was altered at some time after plant start-up. The alteration consisted of interchanging the sensor control signals. As a result, the induced-draft fans are presently controlled by the boiler load sensors and the forced-draft fans are controlled by the furnace pressure sensors. This apparently resulted in some degree of improved operation. Since the test program will introduce additional innovations throughout the furnace flue-gas system, preliminary observations indicate the advisability of returning to the original control scheme whereby the induced-draft fans are under the control of the furnace pressure sensors. A more detailed study of this arrangement will be made during the engineering-design phase of the project.

The limestone-injection feed rate to the boiler is controlled by a gravimetric feeder. During periods of additive injection, flow controls on the existing feeder 3 will be set at maximum. Variations in the coal flow required for limestone calcination will be manually controlled from the existing fuel control system.

For acquisition of reliable data from the three experimental test-facility plants, flue-gas flow through each plant is maintained at a constant desired flow rate. Full closing, adjustable dampers, controlled by upstream flow sensors, serve to maintain the flowrate through each plant at the desired level.

Gas flow stoppage in either of the three plants is sensed by high-low pressure sensors, which serve as backup to the induced-draft-fan interlocks. Should an unintentional flow stoppage occur, the pressure sensors will automatically position the slide gates to the appropriate positions for balanced-system gas flow.

Loss of scrubbing liquid to any of the three scrubbers will initiate an alarm in the boiler control room to alert the boiler room operator of a pending test facility shutdown.

Both gas and steam reheat systems are temperature-controlled and adjustable to maintain flue-gas temperatures at the desired level.

The gas reheater is controlled with a temperature control and flame safety system.

12.2.2 Control System Description

The discussion in this paragraph will be limited to that portion of the test facility control system responsible for controlling flue-gas flow and stack temperatures as outlined above (12.2.1). All control functions having any effect upon boiler operation are under the supervision of the boiler operator and performed by him. The amount of flue gas required by the test project will vary in accordance with the particular experiment in progress. Flue-gas flow to the test project, however, is at all times subject to the boiler system demands. Requests for changes in flue-gas allotment are transmitted by the test facility operator to the boiler operator. If the request meets with his approval, the boiler operator will position the slide gates and test-facility-plant dampers to alter the gas-stream division and maintain system balance.

All the devices required by the boiler operator for flue-gas control to the test project are located upon a separate control panel located in the boiler room.

Slide Gate Control and Operation. Five slide gates are located at the inlet to the south precipitator. Detailed study may indicate the advisability of substituting a modulating type damper for one of the slide gates to obtain more precise control over gas flow balance. These slide gates serve to regulate the south gas-flow stream and bypass the required amount of flue gas to the test project. Each gate is operated by a motor-driven screw mechanism controlled from a manual control station on the boiler room control panel. Position sensors transmit gate position to indicators located adjacent to each control station. Local control stations are also provided adjacent to each gate for purposes of maintenance.

Automatic gate-operation has been provided to restore gas flow balance quickly in the event of an unintentional induced-draft-fan stoppage in the test facility or underpressure in any of the three lines. Gas flow balance is restored by automatic repositioning of the gates.

Limit switches attached to each gate serve to limit the gate opening automatically by a predetermined amount in accordance with the number of scrubber systems out of operation (i.e., 1/3, 2/3, or 3/3).

Balanced boiler gas flow depends upon the maintenance of a balanced flow in the north and south gas stream outlets from the boiler. To enable the operator to monitor these two gas streams, pressure sensors are installed in each gas duct, upstream of the existing air heaters. Pressure indicators indicate the pressure differential between the two gas streams. A high-low alarm will attract the boiler room operator's attention to any line pressure differentials exceeding predetermined limits.

Scrubber Plants - Flue Gas Control and Operation. Plant lines 1 and 2 are similar, with the exception that the flue-gas reheater on Plant 1 is gas fired and the reheater on Plant 2 is steam heated. The flue gas on Plant 3 is reheated by a recycling hot water regeneration system. Each scrubber plant is designed to process a maximum amount of flue gas equal to 1/6 of the maximum boiler output. Gas flow through the lines is controlled by full-closing dampers on the inlet end of the line. Flow continues down the line through the scrubber and gas reheaters to the induced draft fans, where it is discharged through the stacks to the atmosphere.

The flow-control dampers at the head of the lines are controlled by flow sensors located upstream of the scrubbers. During normal operation, these dampers are on automatic control to maintain a constant flow rate through the process line. Since these flow rates affect boiler operation, gas flow is under the supervision of the boiler room operator. Flow indication and manual-automatic control stations are located on a panel in the boiler control room. Requests for changes in gas flow rate are transmitted to the boiler room operator; at his discretion he will make the necessary set point changes.

During periods when boiler loading is below maximum or varying, automatic load control is applied to the test project. As discussed above, flue-gas sharing is normally on a 50-50 basis. Therefore, whenever boiler gas output decreases below the 50 percent level required by the test project, a load-limiting control determines which of the scrubber systems will continue full-level operation and which will operate on reduced gas flow or suspend the experiment temporarily.

A load-level signal from the boiler load sensor to the test facility master controller will serve to load the test facility system in accordance with the available amount of flue gas. Any reduction in available flue gas will transmit a signal from this master controller to a load control unit. The load control unit will then sum the total flow rate through the three scrubber systems. Upon receiving a cutback signal, the load controller will endeavor to hold as many lines as possible at full flow rate.

At any time, the test facility operator can insert instructions into the load controller, indicating his order of preference for holding any of the lines at full gas flow. For example, he may select Plant 2 as first preference, Plant 1 second, and Plant 3 third. In this case, if the available gas should drop by some small percentage, the load controller would hold systems 2 and 1 at full flow and let the gas flow to Plant 3 vary in accordance with the gas available. If the available gas should diminish further, the lines may continue at full flow, vary with the gas available, or shut down in the order selected. If desired, the load controller may be instructed to operate all lines on balanced flow, varying in unison with the variations in the available gas.

Typical boiler load curves indicate that steam load variations tend to constant weekdays, with short-period dips to 70 to 80 percent of load between 2:00 am and 6:00 pm. Saturday variations are more erratic, ranging from 80 percent of full load, between 2:00 pm and 5:00 pm, with dips to 60 percent between 1:00 am and 2:00 am. Sunday loading varies between full load to 70 percent between 9:00 am and 11:00 pm, falling off to 40 percent between 11:00 pm and 9:00 am. Such variations are representative of plants that are not operated as base-load units.

During weekdays, it is anticipated that the test facility can operate three lines at full capacity, with minor cutback during the low period;

i.e., two lines operating at full capacity with one line varying with the load. During weekends, the test facility will operate between full load and partial load as determined by the available flue gas.

The detailed engineering design phase will determine the operating schedule and level of operation. By shifting boiler load from other units to the test project boiler, full-scale operation may be possible at all times.

Provisions have been made to control stack plume emission by reheating the flue gas before it enters the stacks. Reheat on Plant 1 is by direct gas firing. Burner jets are installed on the periphery of the gas duct and burn into the gas stream in an upstream angular direction. Combustion air to the burners will be furnished by a separate fan. Flue gas in Plant 2 is reheated by a steam coil reheater. This reheater is of the finned-tube type, constructed in modular form. It is mounted in the flue gas stream. In both systems, flue gas temperatures are controlled by temperature controllers activated by temperature sensors that are located at the entrance to each stack. Regeneration is employed for Plant 3 flue-gas reheat. The regenerative system is composed of two heat exchangers, one upstream and one downstream of the scrubber. Flue-gas temperature control is by manually positioning a hand control valve in the bypass lines of the upstream exchanger.

12.3 FLUE-GAS SCRUBBING

Most of the conventional instrumentation for pressure, temperature, flow and level is discussed under Scrubber Systems, Section 3.4. Instrument specifications are presented in Appendix B.

Special instrumentation is limited generally to the following items.

- Analysis of the gas stream. For determination of the CO_2, H_2O, N_2, and O_2 content of the gas stream, it is proper to use two four-stream gas chromatograph analyzers for the gas analysis of the entire facility.

  One chromatograph will be assigned to the scrubber inlet gas streams and one will be assigned to the scrubber outlet gas streams. A gas switching arrangement will permit drawing gas samples from any of the three flue-gas lines for introduction to the appropriate chromatograph. Analysis of the gas stream for SO_2 will be on a continuous basis, by either infrared or ultraviolet methods. Analysis will be located in each of the three lines at both the gas inlet and outlet ducts to the scrubbers.

  Gas samples for SO_3 analysis will be obtained by grab sample means for analysis by the conductivity method.

- Slurry flow will be metered with magnetic-type flowmeters and density will be measured by radioactive techniques.

- Provision for taking grab samples of the slurries for laboratory analysis are shown on the flow diagrams.

- Level measurements in the vessels containing slurries will be made by differential-pressure-type instruments with air purged diptubes to keep solids out of the instruments.

- Pressure instruments in slurry service will have diaphragm seals and will be purged to keep solids out.

- Temperatures will be measured by thermocouples except for the gas reheat control transmitter, which will use a resistance-bulb-type instrument.

12.4 SLURRY AND WASTE SOLID HANDLING

The conventional instrumentation for pressure, temperature, level and flow is discussed under Scrubber Systems, Section 3.4.

Special instrumentation is limited generally to the following items:

- Slurry sampling and metering is described in Section 12.3.
- Belt scales are used for weighing the wet cake from the filters and the centrifuge. Determination of the solids/water ratio must be made by testing grab samples.
- The system is flushed by filling the process water hold tank and circulating process water through various parts of the system. A level switch is provided for controlling the valves as the tank fills.

Dust sampling will be done by the highly accurate isokinetic probe system. Isokinetic sampling is a means of withdrawing a sample such that the velocity through the sampler is the same as the velocity through the duct at the sampling point. Exact procedures for dust loading measurements are described in "Test Procedure for Gas Scrubber," published by the Industrial Gas Cleaning Institute and will be used for determining dust loading at the inlet and outlet of the scrubbers.

The collected dust will be analyzed for calcium sulfate, calcium oxide, magnesium sulfate, magnesium oxide, calcium carbonate, magnesium carbonate, and flyash. It is anticipated that this analysis will be carried out at a laboratory away from the plant site.

12.5 DATA ACQUISITION

The primary function of the research facility is to generate data. This information must be precise and collected efficiently in a form suitable for reduction and analysis by computer. A data acquisition system that meets these objectives and minimizes errors resulting from repeated handling of data by technical personnel is required. The comprehensive nature of the test program calls for a modern, high-reliability data acquisition system.

Approximately 100 variables will be generated within the test facility. They will predominantly be electronic signals of the analog type, representing temperature, density, pressure, flow, analysis, etc.

The time required for data collection will vary according to the objectives of the particular test in progress. To retain congruency of data during certain phases of a test run, all associated variables will be recorded in as short a time interval as practical.

To obtain information as accurately as possible, data will be collected by modern data acquisition equipment and stored upon magnetic tape. This tape will be sent to a computer center away from the test facility for processing. The data acquisition unit will be composed of an input-signal conditioner, multiplexer, amplifier, analog-to-digital converter, logic and timing controller, digital display, and magnetic tape recorder. It will have a high-low alarm output and a typewriter readout. There will be provision for manual channel selection to magnetic tape, typewriter readout, or digital display. Access will be provided for manual input to the tape and sampling rates will be manually selective, approximately 1 to 40 channels per second. The data acquisition system will be located in a trailer adjacent to the scrubber area.

Two methods of data handling were considered, the semi-manual and electronic. Evaluation of either system is complicated by the limited information available from a preliminary design effort. The design engineering phase, however, will produce sufficient detailed information for the evaluation and selection of a specific data system.

12.5.1 Semi-Manual System

The semi-manual system is composed of a number of multi-point and single-point strip-chart recorders, recording data on strip charts. The human effort in manhours and the tendency to error in transposing data from strip charts to punch tape or cards tends to reduce the reliability factor to a level inconsistent with the accuracy of the final results required. For accuracy and speed, the transposed data is computer processed (manual calculation would be impractical). Since take-off from charts is tedious, detailed work, it would probably best be performed by women.

Accuracy is a major determining factor. Due to the large amount of data to be processed, fatigue and the monotony of repetition would unavoidably produce a relatively high rate of error, and errors could cause experiments to be scrapped or require costly, time-consuming effort for their correction. Undetected errors would have detrimental effects upon the final outcome of the project.

The cost of a semi-manual system would be approximately as shown in Table 12-1. The assumptions used are intended to reflect the minimum cost.

Table 12-1

COST OF SEMI-MANUAL DATA ACQUISITION SYSTEM*

Item	Cost
Recorders: 10 @ $1500 each (average)	$ 15,000
Chart Paper: 4320 rolls @ $5.20/roll (216 rolls/year/recorder for 2 years)	21,600
Recorder Maintenance: 3 technicians (1/shift) @ $15,000/year each for 2 years working 10 percent of time	9,000
Data Transposition: 11 transposers @ $12,000/year each for 2 years (1 variable/recorder x 60 min/yr x 300 days/yr x 10 recorders x 0.30 use factor divided by 115,200 min/yr/transposer)	264,000
Total	$309,600

* Based on 100 input variables, 24-hour-per-day operation 300 days per year and a system use factor of 0.30. Salaries include overhead.

To the $309,600 total must be added the cost of the control panel indicators. Consideration must also be given to the dollar cost of transportation errors and their effect upon the validity of project results. Even were the data transposition time reduced to as much as one-third of the estimated totals, the manhour cost plus the human limitations on reliability would remain an excessive value.

12.5.2 Electronic System

The data acquisition system contemplated for the limestone-scrubbing project is intended to fulfill the following functions:

- Replace nearly all process indicators on the control panel

- Provide typewritten readout of any or all variables, as desired, for operation and control of the project
- Record all data on magnetic tape suitable for computer processing
- Provide an automatic typewriter printout, indication light, and audible alarm for all off-limit channels
- Provide, on operator demand, a digital, control-panel readout of process variables

The systems suitable for electronic data acquisition are readily available and produced by numerous manufacturers. They have been used for applications such as power plant control, process control, and numerous types of data acquisition. The system to be used in the limestone scrubbing plant is similar to the acquisition system used in strain-gauge work and with appropriate signal conditioning will be fully applicable.

The system will accept approximately 100 inputs from RTD and thermocouple temperature sensors, flow and pressure sensors, and analytical devices including those with manual input to the data system. Signals from these sources will be measured by an integrating digital voltmeter and the resulting data logged on magnetic tape or widecarriage typewriter.

The system will be equipped with a limit and memory detector unit, which will be used to store two limit values for every input channel. As long as the measured value for each channel is between the two stored limits, the data will be logged in the normal manner. Should an out-of-limit condition occur, an alarm indicator will be illuminated and the data printed in red on the log sheets and recorded on magnetic tape.

A digital clock will be included for automatic system control and time data logged as the first word on each line of the log sheets and the the magnetic tape. Data will be logged in engineering units. No provision is made for computation.

Data will be logged in engineering units. No provision is made for computation.

Based on preliminary study, the cost of the electronic data acquisition system will be approximately $80,000. Switching and digital readouts for the main control panel will be approximately $10,000. Total cost will thus be $90,000.

Although the material costs of the semi-manual system are less than those for the electronic system, the higher operating costs of the semi-manual system for the two-year test period would exceed those for the electronic system. The electronic data acquisition system, in sum, offers more in reliability, speed, economy, and latitude of application. Depending on detailed engineering analysis, either a cathode ray tube, bargraph data display or multi-point strip-chart recorder will be provided for the operator's use during start-up and shut-down. The cathode ray tube would display a maximum of any 50 input channels at a time in bargraph form showing instantaneous changes within the system being monitored. High-low alarms would alert the operator to off-limits variables. The approximate cost of the cathode ray tube bargraph and switching facility would be $8,000 and of the multi-point strip chart recorder and switching facility $4,000. It is felt at this time that adequate information would be provided through the facilities of the electronic data acquisition system. Later analysis of control procedures may indicate that certain elements of this system can be dispensed with.

12.5.3 Control Console

All automatic control and monitoring functions are carried out from a main control console located within the trailer. Depending on final engineering analysis, the control console will either be vertical or have a sloping front panel.

The entire process system will be represented in a graphic form on the panel. Switches, indicating lights, controllers, etc., will be located at appropriate points upon the graphic pattern, with status lights located at each control point. The panel will be divided into three sections, each section representing one of the three process plants. Either thumbwheel or momentary-press switches will serve to call out the value of any variable associated with any of the control projects. These variables will be indicated upon a visual digital display located above the control panel.

Alarms for pump motors and other equipment not associated with the data acquisition system will appear on a back-lighted annunciator panel located at the top of the panel. The typewritten readout from the data acquisition system will be installed as a part of this console.

Section 13

START-UP, OPERATION, MAINTENANCE, AND SHUTDOWN

13.1 START-UP PROCEDURE

The first step in the start-up procedure is to fill the system with water. Water will enter the system via the rinse water line, which enters the inlet side of the scrubber process water pumps. The liquid hold capacity of one scrubber system is approximately 250,000 gallons. It is anticipated that water will be pumped into the system at a minimum rate of at least 1000 gpm. However, this flow may be changed for certain periods of time to the flow anticipated in the next run; this period will be used for calibration of flow meters.

When the scrubber effluent tank reaches its control level, scrubber effluent pumps will be started, with the liquid being pumped directly to the clarifier. When the clarifier is approximately 3/4 full, gas flow will be started into the scrubbers, the clarifier underflow pumps started, and the vacuum filter or centrifuge started. At this time, the reheat system will also be started.

Within a short time, the clarifier will begin to overflow and fill the process water hold tank. When this tank reaches control level, the fill water will be shut off, the valve out of this tank to the scrubber process water pumps opened, and the system will be operating normally.

13.2 SHUTDOWN PROCEDURE

The first step in shutting down the scrubber system will be to close the dampers in the inlet duct and to shut down the reheat system. Liquid will continue to recirculate through the system until it is cooled sufficiently to assure no cementing in the scrubbers. When the scrubber has cooled sufficiently, the liquid flows will be shut down in the following order: scrubber process water pumps, scrubber effluent pumps, clarifier underflow pumps, and finally the filtrate return pump. The last step in the shutdown will be turning off the vacuum filter and the filter solids conveyor.

An alternate procedure will be used if it is desired to rinse and drain the system completely. In this procedure, the first step will again be to shut off the inlet flue gas and the reheat system. Then the rinse water valve will be opened and subsequently the outlet valve for the process water hold tank closed. Rinsewater will be pumped through the scrubber process water pumps to rinse out the scrubber feed lines and the scrubber before returning to the process water hold tank. During the rinsing operation, the level in this tank will rise from the normal five-foot level to the eight-foot level. At this level, the rinsewater will be shut off by an automatic level controller. The scrubber bypass line will then be opened and the scrubber feed line closed before the outlet valve for the process water hold tank is opened. The water in the system will then be circulated through the scrubber effluent hold tank, the clarifier, the process water hold tank, and back to the scrubber effluent hold tank until all suspended solids have been removed by the vacuum filter. When softening is required prior to discharge, as may be the case in experiments with dolomite injection, softening chemicals (hydrated lime $Ca(OH)_2$, soda ash Na_2CO_3, and sodium silicate Na_2SiO_3) will be added in required amounts during this recirculation and the precipitate removed by the filter. When the required softening has been achieved, or directly following rinsing when softening is not required, the system will be drained through the clarifier underflow line near the vacuum filter. During draining, the makeup water line valve and the rinsewater valve will be kept closed by manual override of the automatic low-level controller in the process water tank. To achieve a final system rinse, the makeup water valve will be opened for a brief period of time when the process water has been drained off. The lines will be drained at the low points if a new experiment is not initiated directly. The scrubber effluent tank cannot be drained by pumping and must be drained manually at the solids conveyor screw.

13.3 SWITCHOVER

In case of an emergency, the mill must be returned to coal pulverizing service. The following sequence of action is contemplated:

- Notify test operator that test program must be interrupted.
- Stop gravimetric feeder.
- Close slide gate in the limestone feeder line.
- Turn down volumetric feeder.
- Run mill dry.
- Establish ignition.
- Open slide gate in coal feeder line.
- Start to increase rate in coal feed.
- Switch coal feeder to automatic combustion control.
- Open slide gates at south precipitator inlet.
- Close main isolation damper in flue-gas bypass duct.
- Automatic draft control will transfer load from scrubber ID fans to existing ID fans.
- Stop scrubber ID fans after adequate purging of the scrubbers.

In the event that the pulverizer is to be transferred from coal pulverizing to limestone grinding, the procedure can be outlined as follows:

- Notify test personnel.
- Ascertain that adequate limestone reserve is available in the bunker.
- Remove coal feeder control from the automatic mode and switch to remote manual control.
- Turn down coal feeding rate to zero.
- Close coal feeder slide gate.
- Run mill dry.
- Bypass ignition circuit for burners of mill 3.
- Start gravimetric feeder and set at zero feed rate.
- Set volumetric feeder at maximum feed rate.
- Open slide gate of limestone feeder tube.
- Slowly set required limestone feed rate.
- Notify test personnel that additive feeding has started.
- Start scrubber ID fans.
- Slowly open main isolating damper in bypass duct.
- Close (or partially close; if all three scrubbers are not operating) slide gates at south precipitator intake.
- Put scrubber inlet damper controls on automatic.

13.4 ADDITIVE HANDLING OPERATION

The basic additive receiving system is designed for truck delivery, but, occasionally, arrival of carloads of limestone from sources further away is anticipated. If the material arrives by railroad cars at the plant, they will be emptied by the newly erected car dumper of the extended coal handling system at the plant. Agreement must be reached with the power plant management concerning timing and handling of the additive carrying cars, so that this operation causes minimum interference with normal coal handling operations.

If plant scheduling does not permit the emptying of additive material with the railcar dumper, a local railroad yard may be utilized to unload the railcars and load the trucks. This yard should be near the power plant to reduce truck hauling time.

In the event the car dumper is scheduled to handle limestone, the coal on the conveyor system must be emptied. While the coal conveyors can be used for limestone transportation, the stack-out system, live coal pile, and retrieving conveyors require more preparation to handle the limestone. The simplest procedure, in case of rail delivery, would be to take the limestone from the car dumper straight up to the coal bunker in the boiler house. On occasions where this would prove to be impractical, special arrangements must be made to pick up the limestone at the stack-out conveyor and deliver it to the designated storage area west of the crusher house.

The additive handling operation in the storage area will utilize a seperate front-end loader which will permit independence and complete flexibility to support the test program. For instance, it will permit building separate piles of limestone and dolomite of different origins; it will also accommodate, to a limited extent, mixing the additives. The front-end loader will be used to break up the live pile when freezing interferes with free feeding of the material. It is expected that repeated overrun by the loader of the pile above the transfer hopper will prevent arching of the additive due to stickiness caused by rain.

The operation of the conveying facilities from the transfer hopper to the boilerhouse bunker must remain under the direction of the power plant operators, as the additive transport here is accomplished by coal handling facilities serving all seven units of the power plant.

An agreement must be reached to allocate time for limestone transport. The plant personnel will be asked to cooperate in keeping the test personnel fully informed as to timing of conveyor availability, maintenance, shutdown, and other activities which may affect the supply of additives to the boiler.

The actual operating functions for the Redler conveyor and the coal conveyors used for limestone delivery will be done by plant personnel. Coal handling operating procedures will apply to the conveyors when additives are carried.

Operating procedures established for the primary fans and pulverizer of Boiler 1 will apply to mill 3 and its supply fans during limestone grinding service. The unit operator in the unit control room will control the starting and stopping of the mill and fan. Good cooperation must be established between the unit operator and test personnel so that any planned change in mill operation is known in advance to both parties. The control of the mill during limestone grinding will be taken off the automatic combustion control system and replaced by remote manual operation from the unit control panel. As the existing volumetric feeder will not be removed, it must be set at the maximum flow rate so as not to interfere with the operation of the new gravimetric feeder. The new feeder will also be operated by the unit operators, who will follow a predetermined schedule or satisfy momentary requirements coming from the test personnel.

13.5 FLUE GAS HANDLING OPERATION

The operating, startup, and shutdown procedure described previously was extended to the flue-gas handling operation in order to complete the sequence of a full switchover from coal to limestone handling and vice versa. It must be emphaized that all the operating functions in the flue gas handling system which might influence boiler operation must be performed by the plant operating personnel from the unit control room. Such functions as opening and closing dampers and slide gates and starting and stopping ID fans fall within this category. Proper cooperation must be established so that these operating functions should cause minimum disturbance in the conduct of the test program. In the event of an unscheduled change in boiler conditions, it is expected that the test personnel are notified immediately, if possible and if time permits, before any of the flue-gas handling devices are reset. When test personnel want to initiate unscheduled changes in flue-gas flow, they must notify the unit operator. There is always the possibility of reducing gas flow through one or all of the scrubber systems, e.g., through partially opened slide gates which permit the excess flue gas to pass through the precipitator. Increasing the flue-gas flow, if so desired by the test personnel, will be possible only to the extent that load can be shifted to unit 1 from other units. This requires consent of the load dispatcher.

Another method to increase the gas flow through one or two of the scrubber systems, irrespective of the boiler load, would be by starving or stopping one or two of the other scrubber systems. The automatic flow control through the scrubbers is designed so that such an operation is possible without interfering with the operation of the unit.

As an example, a sequence of action is described below, indicating a possible procedure for shutting down one of the scrubber systems when the boiler is running at full load and the scrubber shows signs of excessive clogging:

- Test personnel notify control room that scrubber must be taken out for cleanup.
- Unit operator opens slide gates to pass one third of gas flow, simultaneously closing the branch damper to the particular scrubber.

- Air intake is opened on ductwork to permit purging air to enter.
- Scrubber ID fan of isolated system is kept running until gases are adequately purged from the scrubber.
- Automatic draft control shifts load to existing ID fans and strives to keep the gas flow through the still-operating scrubber systems unaffected.
- ID fan of isolated scrubber is stopped and operating personnel are notified that work can be started on the scrubber.

13.6 REHEATER OPERATION

The reheater systems are operated by the test personnel, but any unexpected major change in reheat rate must be brought to the attention of the unit operator in advance.

The three different reheater systems require different operating procedures. A possible operating procedure is described below for each of the three reheater systems:

- Gas Reheater:

  After the flue-gas flow is established through the scrubber exhaust duct, the reheater combusion air fan is started.

  Next, the igniter is activated and the gas valve opened. The flame safety system will prevent opening the gas valve if the igniters are inoperable. The reheat temperature control can then be put on automatic after the desired exit flue-gas temperature is set.

  In case of failure of the reheater combustion air fan, the interlock will automatically shut down the gas supply valve. Interlocking with the ID fans assures flue-gas flow prior to ignition.
- Steam Reheater:

  The steam supply valve is opened by remote control, the required exit gas temperature set, and the steam supply switched to automatic temperature control. The steam trap assembly, condensate tank, and condensate pump will automatically remove condensate and return it to the plant.

If differential pressure gauges indicate excessive clogging in the steam reheater, a backwashing operation must be performed. It is expected that this can be done while the scrubber system is still in operation. The reheater is so arranged that the washwater drops by gravity into the scrubber and, it is hoped, the mist carryover to the fan can be kept to a minimum. If experience shows that this cannot be accomplished without risk of excessive deposit on the ID fan impeller, then the scrubber load has to be reduced for the duration of the backwashing operation or the fan must be completely shut down. Before such an operation, the unit operator should be notified to divert the gas load from the scrubber.

- Regenerative Reheater:

  The operation of this system is started by the circulator pump. No control or supervision is required except monitor of clogging conditions through the heat extractor and reheater surfaces by differential pressure gauges. Air blowing of the heat extractor can be accomplished without changing the load on the unit. Backwashing the reheater surface, however, will require the same precautions as described for the steam reheater.

13.7 AIR PREHEATER MAINTENANCE

The Ljungstrom-type air preheaters of the boiler are occasionally washed down to remove deposits and restore heat transfer capability. It cannot be predicted how the clogging characteristics of the air preheaters will be changed, due to the increased dust loading and the change in fly-ash components.

It is possible that the high dust load will necessitate more frequent washing down of the air preheaters. It is also conceivable that the substantially increased CaO content of the fly-ash will cause formations of deposits in the flumes beneath the air preheaters. If this is the case, the following measures must be taken to assure trouble-free operation of the boiler during the SO_2 scrubbing experiments:

- The sludge drain lines under both north and south air heaters must be enlarged to facilitate drainage of the sludge during washdown.
- Water nozzles should be installed along the bottom of the flume where the sludge is collected, in order to clean the bottom and prevent excessive deposits.

The precautions listed above may be required even if no cementing tendency is detected in the sludge, as the bottom of the flumes in question have a very modest slope and heavy sludges will not drain by gravity.

13.8 OPERATION DURING MALFUNCTION

Provisions for maintenance of operation during malfunction have been made through two modes. The first is the use of two pumps in parallel on all main process streams. The second is the use of controls and alarms on the main process flow lines. Two pumps are used in parallel on the scrubber effluent, the clarifier underflow, and the scrubber process water return lines. These pumps are each designed to handle approximately 75 percent of the anticipated maximum flow in the lines. Thus, if a pump fails, some flow through the system can be maintained.

Controls and alarms are placed at three key points in the process: (1) the process water return line; (2) the level of the scrubber effluent hold tank; and (3) the level of the process water hold tank. If the flow of process water falls below a set minimum value, an alarm will warn the control room operator to shut down the damper which controls the inflow of flue gas. Prevention of hot gas from entering the scrubber when no water is flowing through it is important to prevent cementing of solids in the scrubber.

A liquid-level alarm system is provided in the scrubber effluent tank. If the level in this tank rises above the control point, this system will actuate an alarm in the control room and simultaneously close down the flow of process water to the scrubber.

The process water hold tank is ten feet high. During normal operation, it will be controlled at the five-foot level. If the scrubber process water pumps fail or the return lines to the scrubber plug, water will continue to overflow the clarifier and fill this tank. At the same time, the level in the scrubber effluent hold tank will drop, causing the valve which controls the flow out of this tank to close down. Thus, flow to the clarifier will be shut off. The process water hold tank has enough capacity to take the interim flow from the clarifier without overflowing.

If one of the filters breaks down, the centrifuge can be used as the back-up system for solids handling. The change-over will be done manually.

Section 14

TEST PROGRAM

A Test Program Plan has been developed based on program objectives established by the NAPCA and evaluation of available techniques for scrubbing sulfur oxides and particulates from flue gas. The plan provides a basis for selection and location of instrumentation, preliminary process design, and preliminary scheduling of the test program.

The plan as described here represents concepts for establishing a detailed test program in Phase II. It is based on an understanding of the process and scrubber characteristics as developed in Sections 5 and 6. In developing the plan, an effort was made to provide enough detail to aid in the initial planning and engineering stages of this project.

14.1 OBJECTIVES AND SCOPE

Principal objectives of the test program are as follows:

1. Measure, evaluate, and compare the mass transfer capability of the selected scrubber designs.

   This involves determining mass transfer coefficients or SO_2 removal efficiencies and relating these to scrubber design and operating conditions.

2. Develop scrubber performance data and correlations of variables used to design commercial scrubbing systems.

This involves development of design equations or correlations that relate scrubber SO_2 removal efficiency and the principal operating variables that affect it. Examples of operating variables believed to be important are scrubbing solution or slurry composition, gas and solution/slurry flow rates, the relative amounts of SO_2 and additive present in the flue gas, and the state of calcination of the additive.

3. Measure, evaluate, and compare the particulate removal efficiencies of the selected scrubber designs.

   This requires correlation of collection efficiency with the operating variables that affect it. These include scrubbing solution or slurry flow rates, pressure drop, liquid distribution pattern, and particle size.

4. Determine the most favorable operating configuration for the solution/slurry circuit.

   SO_2 removal efficiency is a function of scrubbing solution composition, which is in turn influenced by its residence time in the process equipment and suspended solids concentration. This objective requires finding the flow scheme that results in highest SO_2 removal with minimum additive loss.

5. Determine the performance characteristics of the clarifier, vacuum filter, and centrifuge.

   This involves measuring suspended solids concentration in feed, overflow, and filtrate, and determining the water content of underflow, filter cake, and centrifuge discharge.

6. Measure, evaluate, and compare the operation of three types of flue gas reheaters.

   This involves determining the economics of each reheater design when it is operating at a level required to prevent plume formation for a specific set of meteorlogical conditions.

7. Determine accurate overall material and energy balances.

   These are needed for economic evaluations. Because of the large scale of the test facility, data should be representative of commercial operation.

8. Identify, evaluate, and solve problems related to mechanical design.

   These problems have to do with plugging and scaling in lines and equipment, corrosion testing, etc.

9. Point out where small-scale supporting research is needed to help accomplish program objectives.

Table 14-1 summarizes the major objectives of the test program. It further describes measurements to be made, analytical techniques to be used, and how to apply these data to commercial design.

14.2 APPROACH

The first phase of the test program will consist of initial start-up to check out equipment, piping, wiring, and controls. This will be followed by a period of performance testing and instrument calibration to prepare the system completely for planned experiments.

The first set of experiments will consist of screening tests designed to identify the principal independent variables that affect process performance. These experiments will also be used to select the mode of system operation that results in best performance. Modes refer to certain optional operating schemes permitted by the process design. For example, operation of the scrubber solution circuit with or without the clarifier represents separate modes. A certain amount of variable correlation is believed possible from the screening tests. The major effort in this direction, however, will come with a later set of experiments.

The portions of the test program that follow and evolve from screening are designated here as primary experiments. These will consist of detailed investigation of performance characteristics to define the process completely in a quantitative way. Results of the screening experiments will narrow the range and permit the primary experiments to concentrate on establishing useful variable correlations. The primary experiments will emphasize generation of data that are required for the design of commercial systems.

The design equations or correlations developed from the data generated by the primary experiments will be based on a process model to be prepared in Phase II. This model will consist of a series of equations relating independent and dependent process variables. It will be derived through the application of chemical engineering theory to the process as it is presently understood.

In the process model, the process variables will be related by a series of coefficients. The numerical value of these coefficients will be determined from the data generated in the primary experiments through the use of regression analysis.

Mechanical design development will proceed concurrently with the process-oriented tests. Hopefully, any problems such as the plugging of lines and equipment can be solved during the start-up period. Problems in the mechanical category, such as corrosion testing, will be evaluated by standard methods carried out over the entire test program.

Because of the large scale of the test facility, it is important to obtain the maximum amount of significant data with the minimum number of test runs. For this reason, statistical specialists will work closely with process engineers to establish a statistical design of experiments.

In addition to the experiments to be carried out at the test facility, some small-scale laboratory experiments will be required to develop basic physical property data. Some of the physical properties that

Table 14-1

MAJOR TEST PROGRAM OBJECTIVES AND TECH

What Test Program Will Determine	Means of Obtaining Data	
1. Quantity of SO_2 absorbed by each scrubber over a range of operating conditions	Measure SO_2 concentration of gas entering and leaving scrubber	Infra red or u
2. SO_2-removal efficiency under various scrubber operating conditions	Measure SO_2 absorption corresponding to each set of operating variables: gas and liquid flowrates, inlet gas SO_2-concentration, alkali-solids content of entering gas, pressure drop, scrubber liquor composition, solution pH at various locations in the scrubber circuit, and suspended solids content in scrubbing liquor	Infra red or ul Isokinetic sam inlet gas follo Pressure drop Scrubber liquo analysis pH meter Scrubber liquo tion density m Liquor flows b Gas flows by v
3. Correlation of mass transfer coefficients with operating conditions	Measure SO_2 absorption for each set of operating variables: gas and liquor flowrates, pressure drop, temperature; keep constant scrubber liquor composition.	Measurements pressure drop (2) of this tabl Temperatures Control soluti itor with regul Seek dimensio variable corre

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Table 14-1

PROGRAM OBJECTIVES AND TECHNIQUES

ining Data	Technique	Design Application
entration of gas en- scrubber	Infra red or ultraviolet	For calculation of mass transfer coefficients, absorption efficiency, economics, etc.
rption corresponding rating variables: gas es, inlet gas SO_2- ali-solids content of ssure drop, scrubber , solution pH at vari- e scrubber circuit, ids content in scrub-	Infra red or ultraviolet for SO_2 conc. Isokinetic sampling of particulates in inlet gas followed by chemical analysis Pressure drop by pressure transducers Scrubber liquor composition by chemical analysis pH meter Scrubber liquor solids conc. by radiation density meter Liquor flows by magnetic flowmeter Gas flows by venturi meters	As part of screening tests to establish limits for operating conditions in test facility, also to help select most favorable solution-circuit configurations and establish operating conditions for commercial designs
rption for each set bles: gas and liquor re drop, tempera- t scrubber liquor	Measurements of SO_2 conc., flowrates, pressure drop, as described in (1) and (2) of this table Temperatures by transducers Control solution composition by pH monitor with regulation of alkali addition Seek dimensionless group and specific variable correlations	For scaling commercial scrubber designs and predicting performance characteristics

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Table 14-1 (Cont.)

MAJOR TEST PROGRAM OBJECTIVES AND TECHNI

What Test Program Will Determine	Means of Obtaining Data	Te
4. Correlation between total SO_2 absorption and solution composition, seeking a correlation of SO_2 absorption efficiency as a function of % $CaSO_3$, % total SO_2 in solution, and temperature of solution	Measure SO_2 absorption as described in (1) for a range of solution compositions and temperatures	Measure SO_2 co and determine s chemical analys
5. Particulate removal efficiencies of scrubbers and correlation of efficiency with operating variables	Measure solids concentration of gases entering and leaving scrubbers for varying levels of gas and liquid flowrates, pressure drop, liquid distribution, particle consist, and energy consumption	Methods describ table for flowrat
6. Most favorable solution-circuit configuration	Compare SO_2 recovery efficiency by operating the scrubber-liquor circuit with and without some of the major components (clarifier, hold tanks)	Use of system b urements as des table
7. Effectiveness of calcination of alkali additive	Determine if alkali additive is under-calcined, completely calcined or hard-burned; determine dissolution rate of calcine	Obtain isokinetic gas entering scr Run beaker-scal typical scrubber

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Table 14-1 (Cont.)

ST PROGRAM OBJECTIVES AND TECHNIQUES

btaining Data	Technique	Design Application
bsorption as described ge of solution composi- eratures	Measure SO_2 conc. as described in (1) and determine solution composition by chemical analysis	For predicting absorption efficiency for different solution compositions
concentration of gases aving scrubbers for va- gas and liquid flowrates, liquid distribution, t, and energy consump-	Methods described in (1) and (2) of this table for flowrates, and sampling	For design of commercial units and prediction of performance
ecovery efficiency by crubber-liquor circuit t some of the major arifier, hold tanks)	Use of system bypasses and SO_2 measurements as described in (1) of this table	For design of commercial system
kali additive is under- letely calcined or hard- nine dissolution rate of	Obtain isokinetic sample of particles in gas entering scrubber Run beaker-scale dissolution tests using typical scrubber liquor as solvent	For determining minimum residence time of solution circuit for complete dissolution of lime

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Table 14-1 (Cont.)

MAJOR TEST PROGRAM OBJECTIVES AND TECH

What Test Program Will Determine	Means of Obtaining Data	
8. Optimum particle size for alkali solids	Correlate SO_2 absorption and particulate collection with particle size distribution	SO_2 and parti previously Record of pul and samples l
9. Performance characteristics of clarifier, vacuum filter and centrifuge; settling and filtering characteristics of solids to be removed from solution	Measure percent solids in all liquid streams entering and leaving these pieces of equipment for a range of flowrates and solids loadings	Solids concen viously Moisture cont tifuge solids b Settling chara standard labo cylinder Filtration cha scale filtratio
10. Reheat requirements necessary to prevent plume formation in the stack gas for specific meteorological conditions	Determine the heat balance and heat levels required to prevent plume formation and correlate these requirements with weather conditions	Raise the rehe gree incremen After each inc to establish th tion. Visual c acteristics (Ri tendency, leng (air temperatu wind velocity) types of heate
11. Quantity of NO_x absorbed by each system over a range of operating conditions	Measure NO_x of inlet and exit streams	Infrared or ul

A

Table 14-1 (Cont.)

EST PROGRAM OBJECTIVES AND TECHNIQUES

Obtaining Data	Technique	Design Application
absorption and particu- with particle size dis-	SO_2 and particle removal as described previously Record of pulverizer control settings and samples leaving pulverizer	For specifying commercial process and equipment design
ent solids in all liquid ing and leaving these pment for a range of solids loadings	Solids concentrations as described previously Moisture content of filter cake and centifuge solids by evaporative drying Settling characteristics of solids by standard laboratory tests in graduated cylinder Filtration characteristics by small-scale filtration leaf tests	For specifying size of clarifier, filter, or centrifuge for commercial plant
heat balance and heat d to prevent plume for- rrelate these require- ather conditions	Raise the reheater temperature by 5-degree increments until plume disappears. After each increment allow enough time to establish the new steady state condition. Visual observation of plume characteristics (Ringleman Index, falling tendency, length) and weather conditions (air temperature, relative humidity, wind velocity) will be recorded. Three types of heaters will be tested.	For determining type and size of reheater for commercial operation and predicting operating requirements and economics of commercial-scale reheater
f inlet and exit streams	Infrared or ultraviolet	

B

will be required are indicated in Tables 5-2 and 6-5. Equilibrium data for SO_2 gas over solutions of calcium sulfite, bisulfite, and sulfate are an example of one piece of physical property data that will be required.

Complete specification of all physical property data required for the test program will be made in Phase II. Included in these specifications will be the conditions under which physical property measurements should be made.

14.3 OPERATIONAL MODES

Removal efficiency with respect to SO_2 depends as much upon the chemical balance of the circulating solution as it does on scrubber design. The configuration of the solution circuit exerts one of the most important controls on the chemical balance and solution or slurry composition. For this reason, the test facility is designed to permit the selection of several flow schemes for operating the circuit as well as for using one or more stages of absorption within a scrubber. These options are referred to as modes.

The equipment described in Sections 6 through 11 can be operated in a number of different modes and under a wide range of operating conditions. For example, operation of Plant No. 200 (TCA scrubber) with two scrubbing stages, clarifier in operation, vacuum filter in operation, and no use of coagulants or chemical additives other than those initially present in the injected alkali material, represents one possible mode of operation. Use of the same process flow, but with replacement of the vacuum filter by the centrifuge, represents another mode.

Table 14-2 indicates the operational modes to be investigated for the three scrubbing systems.

Table 14-2

OPERATIONAL MODES, SCREENING EXPERIMENTS

Mode	Scrubber Design	Clarifier	Vacuum Filter	Centrifuge	Coagulant Addition	Heat Extraction	Catalytic Additive
			Plant No. 100				
100-A	Venturi + 1 stage	In	In	Out	n. a.	n. a.	No
100-B	Venturi + 1 stage	In	Out	In	n. a	n. a.	No
100-C	Venturi + 1 stage	In	i. b.	i. b.	n. a.	n. a.	Yes
100-D	Venturi + 1 stage	In	Out	Out	n. a.	n. a.	No
100-E	Venturi + 1 stage	Out	In	Out	n. a.	n. a.	No
100-F	Venturi only	In	In	Out	n. a.	n. a.	No
100-G	Venturi + 2 stages	In	In	Out	n. a.	n. a.	No
			Plant No. 200				
200-A	2 stages	In	In	Out	None	n. a.	n. a.
200-B	2 stages	In	Out	Out	None	n. a.	n. a.
200-C	2 stages	In	In	Out	D-202*	n. a.	n. a.
200-D	2 stages	In	In	Out	Y-201*	n. a.	n. a.
200-E	2 stages	In	Out	In	Y-202*	n. a.	n. a.
200-F	2 stages	Out	i. b.	i. b.	Y-201*or Y-202*	n. a.	n. a.
200-G	3 stages	In	i. b.	i. b.	None	n. a.	n. a.
			Plant No. 300				
300-A	1 stage	In	Out	In	n. a.	off	n. a.
300-B	1 stage	In	Out	Out	n. a.	off	n. a.
300-C	1 stage	Out	In	Out	n. a.	off	n. a.
300-D	1 stage	Out	Out	In	n. a.	off	n. a.
300-E	1 stage	In	Out	Out	n. a.	on	n. a.
300-F	2 stages	In	i. b.	i. b.	n. a.	on	n. a.
300 A-G	2 stages	In	i. b.	i. b.	n. a.	on	n. a.
300 A-H	3 stages	In	i. b.	i. b.	n. a.	on	n. a.

n. a. = not applicable
i. b. = indicated best mode
* = coagulant is injected ahead of these equipment items

In Plant 100 (venturi scrubber), seven system modes will be evaluated in the variable screening phase of the process development test program.

The venturi scrubber configurations to be evaluated are a venturi followed by a single absorption stage, a venturi followed by two absorption stages, and a venturi with no absorption stages. For the screening experiments, this plant will be operated without use of coagulants in the solids waste system and without heat extraction from the gas. Flue gas will be reheated with a gas-fired heater. In one experiment, this plant will be used to evaluate the effect of catalytic additives, such as iron oxides, on process performance.

In Plant 200 (turbulent contact scrubber), seven operational modes will be evaluated. Both two-stage and three-stage scrubber configurations will be investigated. Experiments for the two-stage configuration will include investigation of the effect of sphere design and sphere concentration upon performance. This plant will also be used to evaluate the use of coagulants in the solids waste system. Coagulant addition will be investigated by appropriate analyses at several locations: upstream from the clarifier, between the clarifier and the vacuum filter, and between the clarifier and the centrifuge. The use of coagulants in the operational mode where the clarifier is not in use will also be investigated. Neither the effect of catalytic additives nor heat extraction will be investigated in this plant. Flue gas will be reheated by steam coils.

Eight operational modes and two types of scrubbers (flooded bed and impingement plate) will be investigated in Plant 300 during the variable-mode screening phase. First, both single and double-stage versions of the flooded-bed scrubber will be evaluated. Then, evaluations of two-stage and three-stage configurations of the impingement-plate scrubber will be made. In this plant, neither coagulant addition nor catalytic additive addition will be considered. However, the use of heat extraction upstream of the scrubber will be investigated.

14.4 SYSTEM VARIABLES

Variables are defined here as a system characteristic or condition that can be measured (flow rates, concentrations, etc.). Independent variables are those whose values can be controlled directly by the experimenter. Dependent, or uncontrolled, variables are those whose values are a result of fixing a set of independent variables. For example, SO_2 removal efficiency is a dependent variable. Dependent variables can only be controlled by the experimenter if he knows the quantitative correlation between these two types of variables.

14.4.1 Independent Variables

Thirteen independent variables were selected on the basis of process understanding as developed in Section 5 and 6. Selection was influenced to some extent by the suitability of instrumentation and methods for variable measurement. Tables 14-3 and 14-4 list the independent variables selected for control in the test program. Table 14-3 shows the units for reporting these data and estimated ranges of values; Table 14-4 indicates probable analytical methods and instrument locations on P&ID's. The variables have been divided into five groups to simplify program planning and evaluation.

Inlet flue gas flow rate will be controlled by the damper located immediately downstream from the venturi used for flow rate measurement. The 40,000-acfm flow rate indicated in Table 14-3 corresponds to a scrubber turndown of 42 percent. Inlet flue gas SO_2 concentration will be controlled by monitoring the sulfur concentration of the coal fed to the steam generator and injecting controlled amounts of SO_2 into the

Table 14-3

INDEPENDENT VARIABLES

Variable Description	Symbol	Data Unit	Variation Range
Flue Gas Group			
Inlet gas flow rate	V_1	$ft^3/min.$	40,000 - 94,000
Inlet gas SO_2 concentration	V_2	mole percent	0.10 - 0.35
Inlet gas temperature	V_3	^oF	215 - 275
Additive Group			
Inlet gas CaO concentration	V_4	lbs/ft^3	6.80×10^{-5} - 70.0×10^{-5}
Inlet gas MgO concentration	V_5	lbs/ft^3	0 - 31.0×10^{-5}
Inlet additive size consist	V_6	ft^3/lb	to be determined
Scrubber Operation Group			
Scrubber feed flow rate	V_7	ft^3/min	27 - 440
Scrubber feed solids concentration	V_8	lb/ft^3 soln.	nil = 7.0
Scrubber pressure drop (only applies for venturi scrubber)	V_9	inch H_2O	4 - 10
Scrubber Feed Distribution Group			
Scrubber feed external distribution	V_{10}	wt. percent	0 - 50
Scrubber feed internal distribution	V_{11}	wt. percent	0 - 50
Additional Materials Group			
Coagulant concentration	V_{12}	wt. percent	to be determined
Catalyst concentration	V_{13}	wt. percent	to be determined

Table 14-4

INDEPENDENT VARIABLES

Variable Description	Symbol	Analytical Method	Instrument Numbers
Flue Gas Group			
Inlet gas flow rate	V_1	venturi	J-131, J-231, J-331
Inlet gas SO_2 concentration	V_2	IR or UV	J-147, J-247, J-347
Inlet gas temperature	V_3	temperature transducer	J-113, J-213, J-390
Additive Group			
Inlet gas CaO concentration	V_4	isokinetic sampling	J-143, J-243, J-343
Inlet gas MgO concentration	V_5	isokinetic sampling	J-143, J-243, J-343
Inlet additive size consist	V_6	isokinetic sampling	J-143, J-243, J-343
Scrubber Operation Group			
Scrubber feed flow rate	V_7	magnetic flow meter	J-167, J-267, J-368, J-269, J-1261
Scrubber feed solids concentration	V_8	radiation density meter	J-142, J-242, J-342
Scrubber pressure drop (only applies for venturi scrubber)	V_9	pressure transducers	J-119, J-121
Scrubber Feed Distribution Group			
Scrubber feed external distribution	V_{10}	magnetic flow meters	J-167, J-168, J-367, J-1267
Scrubber feed internal distribution	V_{11}	magnetic flow meters	J-167, J-168, J-367, J-368
Additional Materials Group			
Coagulant concentration	V_{12}	scale	
Catalyst concentration	V_{13}	scale	

steam generator as required. This variable will be continuously measured at the scrubber gas inlet by either infrared or ultraviolet techniques. Data obtained will be verified by wet chemistry. Inlet flue gas temperature will be controlled only for operational modes using flue gas heat extraction. The only system presently equipped for this service is Plant No. 300 (flooded-bed and impingement-plate scrubber).

The ratio of additive to sulfur entering a scrubber will be calculated from the calcium and magnesium oxide concentrations and the SO_2 concentration in the entering gas stream. This calculated value will be used as the true percent of stoichiometric ratio of additive to coal sulfur required for a given SO_2 removal efficiency. To determine loss of additive between the injection point in the boiler and entry into the scrubber, this ratio will be compared with the value calculated from total additive and sulfur fed to the steam generator. This loss is a function of steam-generator and gas-duct design. It will probably have to be determined for specific steam generator designs. However, the data collected at the test facility will serve as a guide for this determination.

A wet-chemistry laboratory, preferably located in a trailer, will serve as a facility in which analyses can be performed and chemical instrumentation calibrated.

Particulates size consist data will be used to determine if an increase in additive surface area has an appreciable effect on scrubber performance. Hence, this variable is expressed in terms of surface area. The procedure for converting from size consist data to surface area will be developed as part of Phase II.

The ratio of additive to sulfur entering the scrubber and the particulates size consist will be controlled by adjusting the additive pulverizer.

Additive fed to the pulverizer will be measured by a gravimetric feeder. Size consist of the material leaving the pulverizer will be determined by sampling. The quantity of sulfur entering the steam generator will be calculated from the coal flow rate as determined by volumetric feeders located above the coal pulverizers and by chemical analysis of the coal.

The flow rate of solution or slurry fed to the scrubbers will be determined by magnetic flow meters. In cases where a slurry is being fed to the scrubbers, density will be determined by radiation meters. Techniques for controlling both the flow rates and the solids concentration of the scrubbing medium are described in Section 12.

For the venturi scrubber, the effect of pressure drop on performance will be investigated. The pressure drop will be determined from a series of pressure transducers. For the other types of scrubbers, pressure drop is expected to remain essentially constant for a given rate and configuration.

For many of the scrubber configurations to be investigated (all 100-Plant modes except 100-F and all 300-Plant modes), the scrubbing solution or slurry is divided into two or more streams. To evaluate the effect of this division, variables V_{10} and V_{11} (scrubber feed external and internal distribution) have been included in the test program. When the scrubber feed is divided into two streams, as in Mode 100-A, variable V_{10} is used. When it is divided into three streams, as in Modes 300-A through G, both variables are used.

In the additional materials group, the coagulant concentration variable is used to define the concentration of coagulant added when an operational mode involving coagulant addition is being evaluated. The trace catalyst concentration variable serves the same purpose when modes employing catalytic additives are being used. The variation range for both values will be determined in Phase II.

The analytical methods chosen for independent variable determination are based on an evaluation of available techniques. In all instances, emphasis has been placed on the selection of reliable, accurate, and easily operable methods.

14.4.2 Dependent Variables

The dependent variables were also chosen on the basis of present understanding of the process. Some of these functions are obviously significant, such as exit-gas SO_2 concentration. Others, such as inlet gas O_2 concentration, may not prove significant. It was concluded that changes in the independent variables could appreciably affect process economics, and that relations involving all of them would be required for calculating operating cost and for sizing process equipment. For the dependent variables, however, a different situation is encountered. Therefore, two types of dependent variables, Type 1 and Type 2, were defined.

Type 1 dependent variables are those believed necessary for calculation of process operating economics. Type 2 dependent variables are those not directly required for operating economics calculations. Also included as Type 2 dependent variables are those believed to be useful for improving understanding of process phenomena, but which do not fit the Type 1 dependent variable definition.

Table 14-5 indicates the dependent variables classified in Type 1. Also indicated are the units to be used for calculations, probable analytical method, and equipment numbers identifying the instruments used for measurement of these variables. The variation range and analytical accuracy for these variables have yet to be estimated. This will be done as part of Phase II.

Table 14-5

TYPE 1 DEPENDENT VARIABLES

Variable Description	Symbol	Data Unit	Analytical Method	Instrument Numbers
Exit gas SO_2 conc.	D_1	mol. percent	UV or IR	J-148, J-248, J-348
Exit gas particulate conc.	D_2	lbs/ft^3	isokinetic sampling	J-144, J-244, J-344
Exit gas temperature	D_3	°F	temperature transducer	J-114, J-214, J-314
Reheated gas temperature	D_4	°F	temperature transducer	J-115, J-216, J-315
System pressure drop	D_5	inch H_2O	pressure transducers	J-119, J-120, J-219, J-220, J-319, J-320
Flow rate to dewater sys.	D_6	ft^3/min	magnetic flow meter	J-133, J-233, J-333
Solids conc. to dewater sys.	D_7	lbs/ft^3 liq.	radiation density meter	J-141, J-241, J-341
Settling rate to dewater sys.	D_8	-----	laboratory tests on samples	
Filter cake discharge rate	D_9	lbs/min	scale	J-145, J-245, J-346
Filter cake moisture	D_{10}	wt. percent	sample analysis	
Filtrate flow rate	D_{11}	ft^3/min	orifice flow meter	J-137, J-237, J-337
Filtrate solids conc.	D_{12}	lbs/ft liq.	sample analysis	
Centrifuge discharge rate	D_{13}	lbs/min	scale	J-246
Centrifuge discharge moisture	D_{14}	wt. percent	sample analysis	
Centrate flow rate	D_{15}	ft^3/min	orifice flow meter	J-238
Centrate solids conc.	D_{16}	lbs/ft^3 liq.	sample analysis	
Makeup water flow rate	D_{17}	ft^3/min	orifice flow meter	J-160, J-260, J-372
Clarifier effluent settling rate	D_{18}	-----	laboratory tests on samples	

The SO_2 and particulates concentration of the gas leaving the scrubbers will be used to establish pollutant reduction levels. The temperature of this gas before and after the reheaters will be used for studies of the reheat economics.

The flow rate of material to the dewatering system (D_G) is defined as the flow rate of the slurry exiting the scrubber effluent hold tank. If, in the operational mode being investigated, the clarifier is in use, this flow represents the input of slurry to the clarifier. If the clarifier is not in use, it represents the input to either the centrifuge or the vacuum filter. The nature of the slurry will be established by analyses.

Variables D_8 and D_{18}, the settling rate for the slurry fed to the dewatering system and the clarifier underflow, will be determined by a series of laboratory settling tests. These tests are described in Section 9.

Filter cake moisture and centrifuge discharge moisture will be measured as a check for the material balance around the filters and the centrifuge.

Table 14-6 lists the type 2 dependent variables.

The inlet flue gas temperature (C_1) is a dependent variable in all cases except at Plant No. 300 when the heat extractor is in service. In this case, the temperature of the gas entering the scrubber is an independent variable. However, the temperature of the gas entering the heat extractor is a dependent variable. The nitrogen oxides concentration inlet and exit gas will be used to determine the efficiency of these scrubbers for removing nitrogen oxides, a pollutant of increasing concern. Concentrations of CO_2, O_2, H_2O, N_2, and SO_3 in the inlet and exit gas will be measured as part of the attempt to define process phenomena better. This is also the reason for determining the chemical composition of the slurry exiting the scrubber.

Table 14-6

TYPE II DEPENDENT VARIABLES

Variable Description	Symbol	Data Unit	Analytical Method	Instrument Numbers
Inlet flue gas temperature	C_1	°F		J-113, J-213, J-390
Inlet gas NO_x conc.	C_2	mol. percent	UV	J-147, J-247, J-347
Inlet gas CO_2 conc.	C_3	mol. percent	chromatograph	J-147, J-247, J-347
Inlet gas O_2 conc.	C_4	mol. percent	chromatograph	J-147, J-247, J-347
Inlet gas H_2O conc.	C_5	mol. percent	chromatograph	J-147, J-247, J-347
Inlet gas N_2 conc.	C_6	mol. percent	chromatograph	J-147, J-247, J-347
Inlet gas SO_3 conc.	C_7	mol. percent	to be determined	-------------------
Exit gas NO_x	C_8	mol. percent	UV	
Exit gas CO_2	C_9	mol. percent	Chromatograph	J-148, J-248, J-348
Exit gas O_2	C_{10}	mol. percent	Chromatograph	J-148, J-248, J-348
Exit gas H_2O	C_{11}	mol. percent	Chromatograph	J-148, J-248, J-348
Exit gas N_2	C_{12}	mol. percent	Chromatograph	J-148, J-248, J-348
Exit gas SO_3	C_{13}	mol. percent	Chromatograph	J-148, J-248, J-348
Chemical composition scrubber effluent	C_{14}	mol. percent	sample analysis	J-171, J-271, J-271
Scrubber effluent pH	C_{15}		pH meter	J-169, J-269, J-369
Scrubber effluent temp.	C_{16}	°F	temperature transducer	J-191, J-291, J-391
Scrubber feed temp.	C_{17}	°F	temperature transducer	J-117, J-217, J-317
Scrubber feed pH	C_{18}		pH meter	J-173, J-273, J-373

14.5 SCREENING EXPERIMENTS

These experiments are designed to determine which independent variables and operating modes are the most significant to system performance. They will also help establish the range of interest for many of the independent variables, such as gas-liquid rates in the scrubbers. A statistical design of experiments will be used to obtain the required data at a reasonably significant level with a minimum number of runs.

Tables 14-7, 14-8, and 14-9 show possible designs of the screening experiments presently proposed for Plant Nos. 100, 200, and 300. In the case of Plant 100, the first experiment (Experiment 100-A) would consist of operating the plant in its A mode, with independent variables V_4, V_7, V_9, and V_{10} (inlet gas CaO concentration, scrubber feed flow rate, scrubber pressure drop, and scrubber feed external distribution) being investigated in all combinations for two levels. In the second experiment (Experiment 100-B), the plant would be operated in Mode B, while independent variables V_1, V_4, and V_5 (inlet gas flow rate, inlet gas CaO concentration, and inlet gas MgO concentration) would be investigated in all combinations for two levels. This pattern is followed until all modes shown for the 100 Plant in Table 14-2 and all applicable independent variables listed in Table 14-3 have been investigated at least once.

In addition to the aid derived from statistical designs, some logic helps reduce the number of runs to be made. For example, an experiment is run at two values of scrubber liquid rate to determine the effect upon exit gas SO_2 concentration. This experiment uses a vacuum filter. Another experiment is to be run at two levels of inlet gas rate to determine the effect upon exit gas SO_2 concentration. This second experiment uses a centrifuge instead of a vacuum filter. The effect of

Table 14-7

PLANT NO. 100 SCREENING EXPERIMENTS

Experiment No.	Mode	Independent Variables*													No. Variables Changed
		V_1	V_2	V_3	V_4	V_5	V_6	V_7	V_8	V_9	V_{10}	V_{11}	V_{12}	V_{13}	
100-A	A	C	C	C	V_L	C	C	V	C	V	V	N	N	N	4
100-B	B	V	C	C	V_D	V_D	C	C	C	C	C	N	N	N	3
100-C	C	C	V	C	C	C	V	C	C	C	C	N	N	V	3
100-D	D	V	C	C	C	V	C	V	C	C	C	N	N	N	2
100-E	E	C	C	C	C	C	C	C	V	C	C	N	N	N	1
100-F	F	C	C	C	C	C	C	V	V	V	N	N	N	N	3
100-G	G	C	C	C	V_L	C	C	V	C	C	V	N	N	N	3

* For identification of independent variables see Table 17-2

C = Constant
V = Variable
N = Not Used
D = Dolomite
L - Limestone

Table 14-8

PLANT NO. 200 SCREENING EXPERIMENTS

Experiment No.	**Mode**	**Independent Variables***													**No. Variables Changed**
		V_1	V_2	V_3	V_4	V_5	V_6	V_7	V_8	V_9	V_{10}	V_{11}	V_{12}	V_{13}	
200-A	A	V	C	C	V_L	C	C	V	C	N	N	N	N	N	3
200-B	B	C	C	C	V_D	V_D	C	C	V	N	N	N	N	N	3
200-C	C	C	V	C	C	C	V	C	C	N	N	N	V	N	3
200-D	D	V	C	C	C	C	C	V	C	N	N	N	V	N	3
200-E	E	C	C	C	C	C	C	C	V	N	N	N	V	N	2
200-F	F	C	C	C	C	C	C	V	C	N	N	N	V	N	2
200-G	G	V	C	C	V	C	C	V	C	N	N	N	N	N	3

* For identification of independent variables see Table 17-2
C = Constant
V = Variable
N = Not Used
D = Dolomite
L = Limestone

Table 14-9

PLANT NO. 300 SCREENING EXPERIMENTS

Experiment No.	Mode	Independent Variables*													No. Variables Changed
		V_1	V_2	V_3	V_4	V_5	V_6	V_7	V_8	V_9	V_{10}	V_{11}	V_{12}	V_{13}	
300-A	A	C	C	C	V_L	C	C	V	C	N	V	N	N	N	3
300-B	B	V	C	C	V_D	V_D	C	C	C	N	C	N	N	N	3
300-C	C	C	V	C	C	C	V	C	V	N	C	N	N	N	3
300-D	D	V	C	C	C	C	C	V	C	N	V	N	N	N	3
300-E	E	V	C	V	C	C	C	C	V	N	C	N	N	N	3
300-F	F	C	C	V	C	C	C	V	C	N	V	V	N	N	4
300A-G	G	V	C	C	V_L	C	C	V	V	N	V	V	N	N	6
300A-H	H	C	C	C	V_L	C	C	V	C	N	V	V	N	N	4

* For identification of independent variables see Table 17-2

C = Constant
V = Variable
N = Not Used
D = Dolomite
L = Limestone

the mode change upon exit SO_2 concentration is probably negligible, so only two experiments instead of four are recommended.

The independent variables and modes selected for study in the test program are based upon the concepts developed in Sections 5 and 6. The functions selected for measurement are considered to be those most directly related to the chemistry, the mass transfer model, and the economic parameters of the system. One possibly important variable that is missing at this stage is the temperature of the scrubber solution. With the present process design, very little control over this variable is possible. This subject will be considered further in Phase II.

Estimated independent variable levels for the screening experiments are shown in Tables 14-10, 14-11, and 14-12. Though these tables show two levels, high and low, it may be desirable to investigate three or more levels for certain variables. Both the number and the values of the levels for each variable will be determined in Phase II.

The statistically significant levels required for the screening experiments have yet to be established. This will be done when more information relating to instrumentation accuracy and the design of experiments has been developed.

Table 14-10

INDEPENDENT VARIABLE LEVELS
PLANT NO. 100 SCREENING EXPERIMENTS

Experiment No.	Independent Variable	Levels^{+}	
		Low	High
100-A	V_4	2.4×10^{-4} (≈110% stoic.)	3.3×10^{-4} (≈150% stoic.)
	V_7	170 (≈14 gpm/ 1000 acfm)	362 (≈30 gpm/ 1000 acfm)
	V_9	6	15
	V_{10}*	40	50
100-B	V_1	70,000	94,000
	V_4	t.b.d. (≈110% stoic.)	t.b.d. (≈150% stoic.)
	V_5	To be calculated	
100-C	V_2	0.20	0.35
	V_6	t.b.d.	t.b.d.
	V_{13}	t.b.d.	t.b.d.
100-D	V_1	Same as 100-B	
	V_7	Same as 100-A	
100-E	V_8	1.3 (≈2% solids)	4.7 (≈7% solids)
100-F	V_7	Same as 100-A	
	V_8	Same as 100-E	
	V_9	Same as 100-A	
100-G	V_4	Same as 100-A	
	V_7	Same as 100-A	
	V_{10}	Same as 100-A	

+For level units see Table 14-2

*$\frac{(V_{10})(V_7)}{100}$ = flow to venturi

t.b.d. = to be determined

Table 14-11

INDEPENDENT VARIABLE LEVELS
PLANT NO. 200 SCREENING EXPERIMENTS

Experiment No.	Independent Variable	Levels$^+$ Low	High
200-A	V_1	70,000	94,000
	V_4	2.4×10^{-4}	3.3×10^{-4}
	V_7	65.6 (≈7 gpm/ 1000 acfm)	188.9 (≈5 gpm/ 1000 acfm)
200-B	V_4	Same as 100-B	
	V_5	Same as 100-B	
	V_8	1.3	4.7
200-C	V_2	Same as 100-C	
	V_6	t.b.d.	
	V_{12}	t.b.d.	
200-D	V_1	Same as 200-A	
	V_7	Same as 200-A	
	V_{12}	t.b.d.	
200-E	V_8	Same as 200-B	
	V_{12}	t.b.d.	
200-F	V_7	Same as 200-A	
	V_{12}	t.b.d.	
200-G	V_1	Same as 200-A	
	V_4	Same as 200-A	
	V_7	Same as 200-A	

+For level units see Table 14-2
t.b.d. = to be determined

Table 14-12

INDEPENDENT VARIABLE LEVELS
PLANT NO. 300 SCREENING EXPERIMENTS

Experiment No.	Independent Variable	Levels^{+} Low	High
300-A	V_4	Same as 100-A	
	V_7	65.6	188.9
	V_{10}^{*}	5.0	10.0
300-B	V_1	70,000	94,000
	V_4	Same as 100-B	
	V_5	Same as 100-B	
300-C	V_2	0.20	0.35
	V_6	t.b.d.	t.b.d.
	V_8	1.3	4.7
300-D	V_1	Same as 300-B	
	V_7	Same as 300-A	
	V_{10}	Same as 300-A	
300-E	V_1	Same as 300-B	
	V_3	215	250
	V_8	Same as 300-C	
300-F	V_3	Same as 300-E	
	V_7	Same as 300-A	
	V_{10}	Same as 300-A	
	V_{11}^{++}	45	60

Table 14-12 (Continued)

INDEPENDENT VARIABLE LEVELS PLANT NO. 300 SCREENING EXPERIMENTS

Experiment No.	Independent Variable	Levels+	
		Low	High
300A-G	V_1	70,000	94,000
	V_4	Same as 100-A	
	V_7		
	V_8	Same as 300-C	
	V_{10}	Same as 300-A	
	V_{11}^{++}		
300A-H	V_4	Same as 100-A	
	V_7		
	V_{10}	Same as 300A-G	
	V_{11}	Same as 300A-G	

+ For level units see Table 14-2

* $\frac{(V_{10})(V_7)}{100}$ = flow to venturi

++ $\frac{(V_{11})(V_7)}{100}$ = upper stage flow

t. b. d. = To be determined

14.6 PRIMARY EXPERIMENTS

As stated before, the purpose of these experiments is to define the limestone injection-scrubbing process in a quantitative way. The data developed will then be used to compare performance of equipment and flow schemes and to provide input for economic calculations. These tests have not been specified or designed yet, but their nature can be discussed.

Table 14-13 outlines primary experiments concerned with scrubber performance and solution circuit configuration. Flue gas reheat, settling and filtering, and mechanical design development are discussed in Section 14.7.

For the modes and variables selected for the primary experiments, a series of factorial experiments will be designed to determine the independent-dependent variable relations required for commercial design. These experiments will allow accurate definition of the response surface for this system. Factors affecting the translation of this surface to larger scale equipment will also be investigated.

The primary experiments will also be used to carry out many of the tests to be described in the Mechanical Design Development Section. Principal examples are materials selection, corrosion tests, and flue gas reheat tests.

Table 14-13

PRIMARY EXPERIMENTS (SCRUBBERS)

Objective	Data Required
Mass Transfer Coefficients in Scrubber	SO_2 material balance, vapor-liquid equilibrium data, area available for mass transfer, temperatures, flow rates
Correlation between Mass Transfer Coefficients and Operating Variables	SO_2 material balances, vapor-liquid data, scrubber surface area dimension, gas and liquid flow rates, pressure drop across scrubber, solution composition, temperature, additive properties
Correlation between SO_2 Removal and Solution Composition	SO_2 material balances, total SO_2 and sulfite concentrations of solution, temperature of solution
Most Favorable System Configuration	SO_2 and CaO material balances, energy balances, pressure drop, pH values, suspended solids in liquor, temperatures of streams, flow rates
Scrubber Particulate Removal Efficiency	Solids material balances, gas flow rates, dust concentrations of gas in and out of scrubber
Correlation of Scrubber Particulate Removal Efficiencies with Related Operating Variables	Material balances, dust concentrations of gas in and out of scrubber, gas flow rate, pressure drop across scrubber, size distribution of dust loading, density of solids, liquid distribution pattern

14.7 MECHANICAL DESIGN DEVELOPMENT

The test program is primarily concerned with measuring scrubber efficiency, investigating modes of operation, and acquiring an extensive body of accurate design data. Most of this information can be obtained by plant instrumentation and standard test procedures. However, many aspects of equipment performance and mechanical design cannot be evaluated from these data. These may require visual observation of performance, trial and error modifications, and special testing techniques. Although some of these aspects are mentioned in other sections of the report, they are summarized briefly as follows.

14.7.1 Plugging and Scaling

Under certain operating conditions, solids carried in slurry or solution may form scale on scrubber walls and internals, in flue gas inlet ducts to the scrubbers, on gas reheater surfaces, and in process piping. Continuous formation and breakup of scale within the scrubber could produce large particles capable of plugging slurry handling lines. Process variables which influence scaling are pH, temperature. and cycle time. However. mechanical design features, such as configuration of scrubber internals, surface characteristics of construction materials, and intensity of shear forces generated within the slurry, may also affect scaling. Some trial and error testing may be needed to determine the most suitable mechanical design.

Buildup of solids can occur on surfaces when slurry handling equipment is taken off-stream and drained. The seriousness of this problem depends upon the adherent characteristics of the deposited solids. Some deposits may be removed by water flushing, if it is done immediately before an exposure to air drying.

14.7.2 Settling and Filtering Characteristics

These properties can best be determined by small-scale testing with a special setup at the plant site, or in the laboratories of equipment manufacturers, or both. Such testing provides accurate data for sizing clarifiers and filters. It also can determine the effectiveness of chemical coagulants and the most suitable filter fabric. Finally, conclusions can be made as to the most suitable type of filter.

Unfortunately, no samples will become available for testing until the prototype plant is built and operating. Since the blinding characteristics of the solids are not known, vacuum-drum belt filters are recommended for the prototype plant. Testing may show that cheaper vacuum disc filters are suitable. Table 14-14 summarizes the general concepts that will lead to a specific set of tests to determine slurry and solids characteristics.

14.7.3 Controls and Operation

It is expected that operation of the prototype plant will demonstrate that certain critical process control designs are suitable. For example, if the boiler load is appreciably reduced, the scrubbing system should adjust smoothly and quickly to the new conditions. This adjustment involves correct response of damper controls while one or two scrubbers are taken off-stream and the flue gas load is shifted from three to one or two scrubbers. Such performance is difficult to predict at this stage, but prototype operation should lead into a well-conceived commercial design.

Table 14-14

SLURRY AND SOLIDS CHARACTERISTICS

Objective	Application	Required (Dependent) Parameters	Controllable (Independent) Parameters	Noncontrollable (Independent) Parameters
Determine Slurry Settling Characteristics	Optimal design of scaled-up clarifiers or clarifier/reactors	Interface settling rate. Compression layer suspended solids concentration and density	Coagulant floc type and concentration. Amount and type of flocculation forces	Alkali type and injection rate. Suspended solids concentration. Particles size distribution. Density (overall). pH. Zeta potential
Determine Slurry Filtration Characteristics	Optimal design of scaled-up filters	Cake yield (batch) Cake total solids conc. Cake bulk density Blinding rate	Form time Filter cloth type of weave Coagulant type and conc. Amount of flocculation forces Amount of precoating and washing Vacuum level	Alkali type and injection rate. Suspended solids concentration. Particles size distribution. pH
Determine Slurry Centrifuging Characteristics	Optimal design of scaled-up centrifuge	Cake discharge rate (continuous) Cake total solids conc. Cake bulk density	Coagulant type and conc. Amount of flocculation	Alkali type and injection rate. Suspended solids concentration. Particles size distribution. pH. Density (overall)
Determine Slurry Floatation Characteristics	Optimal design of scaled-up floatation units	Skimming yield (batch) Skimming total solids conc. Skimming water content Clear liquid total solids conc.	Volume and pressure of air Separation time Coagulant type and conc. Amount of flocculation	Alkali type and injection rate. Suspended solids concentration. Particles size distribution. pH. Density (overall). Zeta potential
Determine Corrosion/Scaling Potential	Choice of material for pipelines, tanks, pumps, etc.	Langhier Index Corrosion sections weight loss/gain scale and corrosion on belts, tanks. Corrosion ticket weight loss/gain.		Alkali type and injection rate. Alkalinity. Time of response. pH
Determine Environmental Pollution Potential and Treatment Requirements for Slurry Released following Shutdown	Scale-up and operation of experimental facility	Ca Concentration Mg Concentration SO_4 Concentration SO_3 Concentration Alkalinity Concentration pH Concentration Suspended Solids Conc. Turbidity Concentration COD Concentration CO_2 Concentration	$Ca(OH)_2$ conc. added NA_2CO_3 conc. added Coagulant type and conc. Amount of flocculation CO_2 conc. added and mode of addition	Alkali type and injection rate

Table 14-14 (Cont.)

SLURRY AND SOLIDS CHARACTERISTICS

Objective	Application	Required (Dependent) Parameters	Controllable (Independent) Parameters	Noncontrollable (Independent) Parameters
Determine Environmental Pollution Potential and Treatment Requirements for Solid Wastes Leachates	Scale-up and operation of experimental facilities	Leachate volume from given solids volume and surface Ca Concentration Mg Concentration SO_4 Concentration SO_3 Concentration Alkalinity Concentration pH Concentration Suspended Solids Conc. Turbidity Concentration COD Concentration CO_2 Concentration	Volume Surface $Ca(OH)_2$ conc. added Na_2CO_3 conc. added Coagulant type and conc. Amount of flocculation CO_2 conc. added and mode of addition	Incident precipitation includes runoff, pH, alkali type and injection rate
Determine Cementitious Properties of the Disposed Solids	Sales as byproduct and stable foundation at land-fill site	Compressive strength-wet curved Compressive strength-dry curved	Time of curving	Alkali type and injection rate
Determine Handling Properties of the Solids and the Slurry	Design of handling equipment	Angle of repose Kelly ball depression Slurry viscosity		Alkali type and injection rate

14.7.4 Materials Selection and Corrosion Tests

Selection of corrosion- and abrasion-resistant materials for this plant does not appear difficult. It seems worthwhile, however, to run corrosion tests in certain areas to determine whether cheaper materials could possibly be used. Appreciable savings could result, especially if plastics could be used. A brief discussion of this subject for certain items of equipment follows:

- Scrubber. 316L was recommended as the safest material. Test spools will be installed inside the scrubber. Each spool should consist of a range of materials such as carbon steel (for standard), Alloy 20-Cb3, 304L, bisphenol A polyester, and baked-on PVC. Additionally, plastic liquor downcomers can be tested for both corrosion and scaling resistance.
- Filters and Centrifuge. 316L appears to be necessary for these items. However, it is suggested that test spools of 304L be inserted on inlets and outlets. Colmonoy 6 hardfacing is recommended for those surfaces of the centrifuge that are subject to abrasive attack.
- Pumps. Alloy 20 appears most appropriate for these items. Testing of less expensive low alloy is worthwhile.
- Clarifier Tank. Steel sides and steel-plate bottom are recommended. However, baked-on PVC lining should be reconsidered.
- Pipelines. Rubber-lined pipe (natural rubber) is recommended for all slurry handling pipes. However, it is suggested that Bondstrand 5000 and baked-on PVC be tested either with spools or in pipe sections.

14.7.5 Flue Gas Reheating

With the three different types of reheaters installed in the three scrubber systems, it will [illegible] possible to conduct a test program which will determine the economics and thermodynamics of flue gas reheating. The main objective of such testing will be to establish the most economical method for reheating the flue gas after scrubbing operation. From a thermodynamic standpoint, the regenerative method would be the most economical. If the heat already available in the flue gas leaving the boiler is used, extra heat input will not be required. This reheating method, however, will show the largest heat-exchanger surface requirement of those systems considered for the same reheating duty.

In order to establish economic parameters, the experiments must be directed toward finding the minimum heat input which can prevent plume formation (or can keep plume formation within tolerable limits). At otherwise constant conditions (with given flue gas quantity, temperature, and moisture content), the formation of the plume and its dispersion in the atmosphere will depend mainly on the following variables:

- Outside air temperature
- Relative humidity
- Wind velocity

In order to establish a relationship between the variables listed and plume formation and diffusion, the test must be arranged in relatively steady weather conditions. Once such steady weather conditions are encountered, the reheating requirements corresponding to these conditions can be established by slowly changing the reheating temperature and observing the change in the opacity of the plume formed, the ascending or dropping characteristic of the plume, and, finally, the complete disappearance of the plume.

For the duration of the test program, the atmospheric conditions affecting plume formation will be measured and recorded. The plume conditions can be registered by observation. During the reheater test program, frequent observation must be made and the coincidence of timing with weather conditions established.

Because any change in the reheating conditions of the regenerative reheater will have an undesirable modifying effect on the scrubber operation proper, it is suggested that the reheater tests be run on the gas- and steam-heated reheaters. Prerequisites for the test runs are:

- Steady-state exit flue gas conditions on the scrubber
- Steady atmospheric conditions

The reheater test should start with zero reheat, time check, observation, and description of the plume. The reheater should then be activated, and the flue gas temperature slowly increased by a five-degree increment. Once the first five-degree increment is reached, a steadying of the flue gas temperature must be awaited, and then a time check made and any change in plume characteristic recorded. Changes to look for are:

- Opacity of the plume
- Falling tendency of the plume
- Length of the plume

After the observations are made and recorded, the next five-degree temperature increment can be undertaken. After each increment, enough time must be allowed for the new steady-state conditions to develop. The time required will depend on the visible length of the plume, wind velocity, and diffusion characteristics. Before the observations of changing plume characteristics are made, the change in plume temperature must reach the visible tip of the plume. Once this condition is attained, the time check and plume observations will be repeated.

The temperature of the exit flue gases should be raised to the point where the visible plume totally disappears. To ascertain the actual temperature at which the plume disappears, the reheat should be reduced very slowly after the last observation until the plume reappears.

The test run itself should then be repeated in the reverse direction, with reductions in the gas temperature by the same five-degree increments between observations.

Test runs should be repeated under as many extreme atmospheric conditions as possible, such as high, medium, and low temperatures; high, medium, and low relative humidities; and high and medium but steady wind velocities and calms. Test runs as described above should be repeated with all possible combinations of the above variables.

14.8 PRELIMINARY TEST PROGRAM SCHEDULE

Figure 14-1 represents the first estimate of a time schedule for the major phases of the test program. In summary, these are:

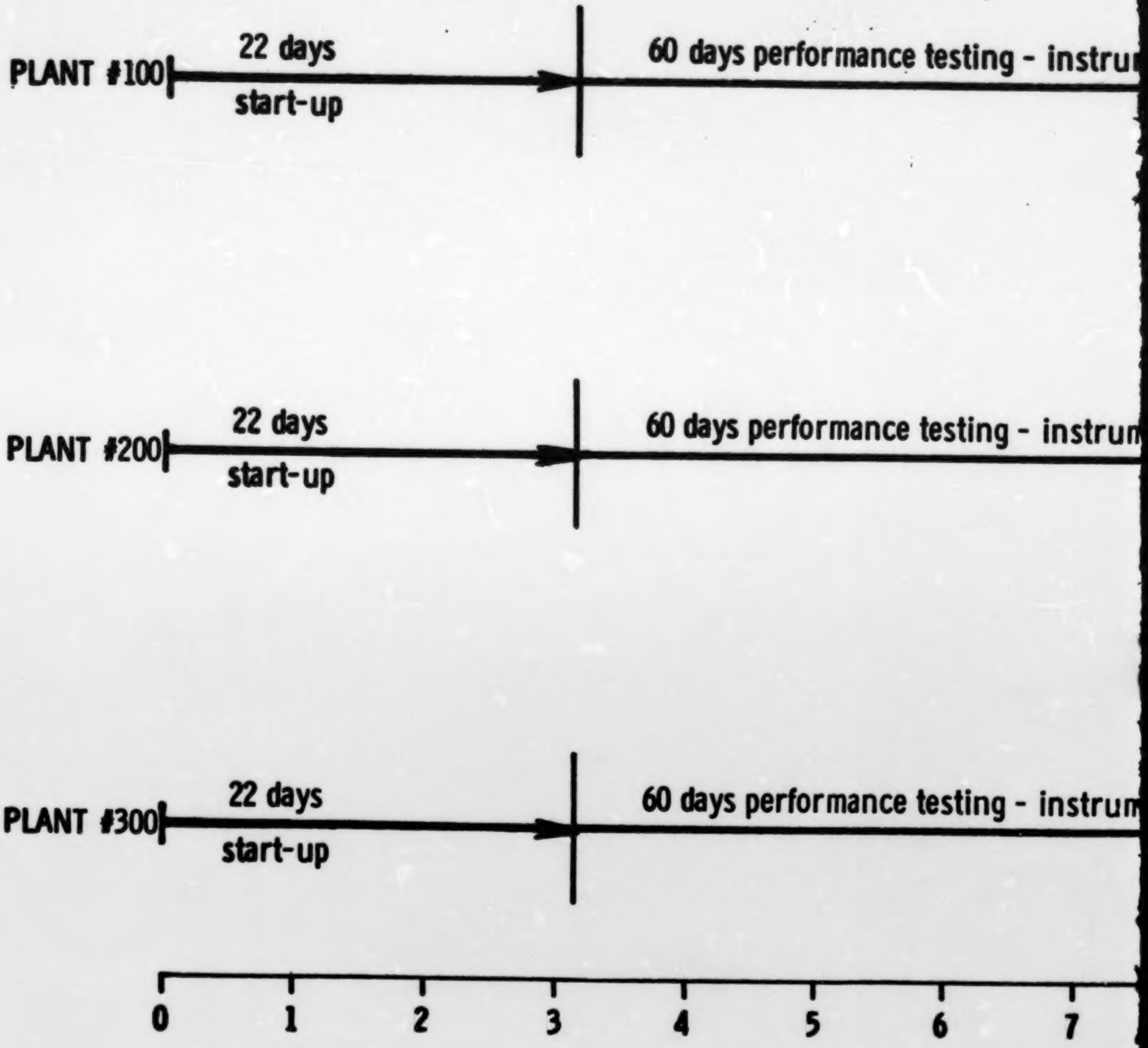
Phase	Duration, months
Start-up	2
Calibration	2
Screening Experiments	2
Primary Experiments	10
Total	16

The start-up period of the test program consists of the following:

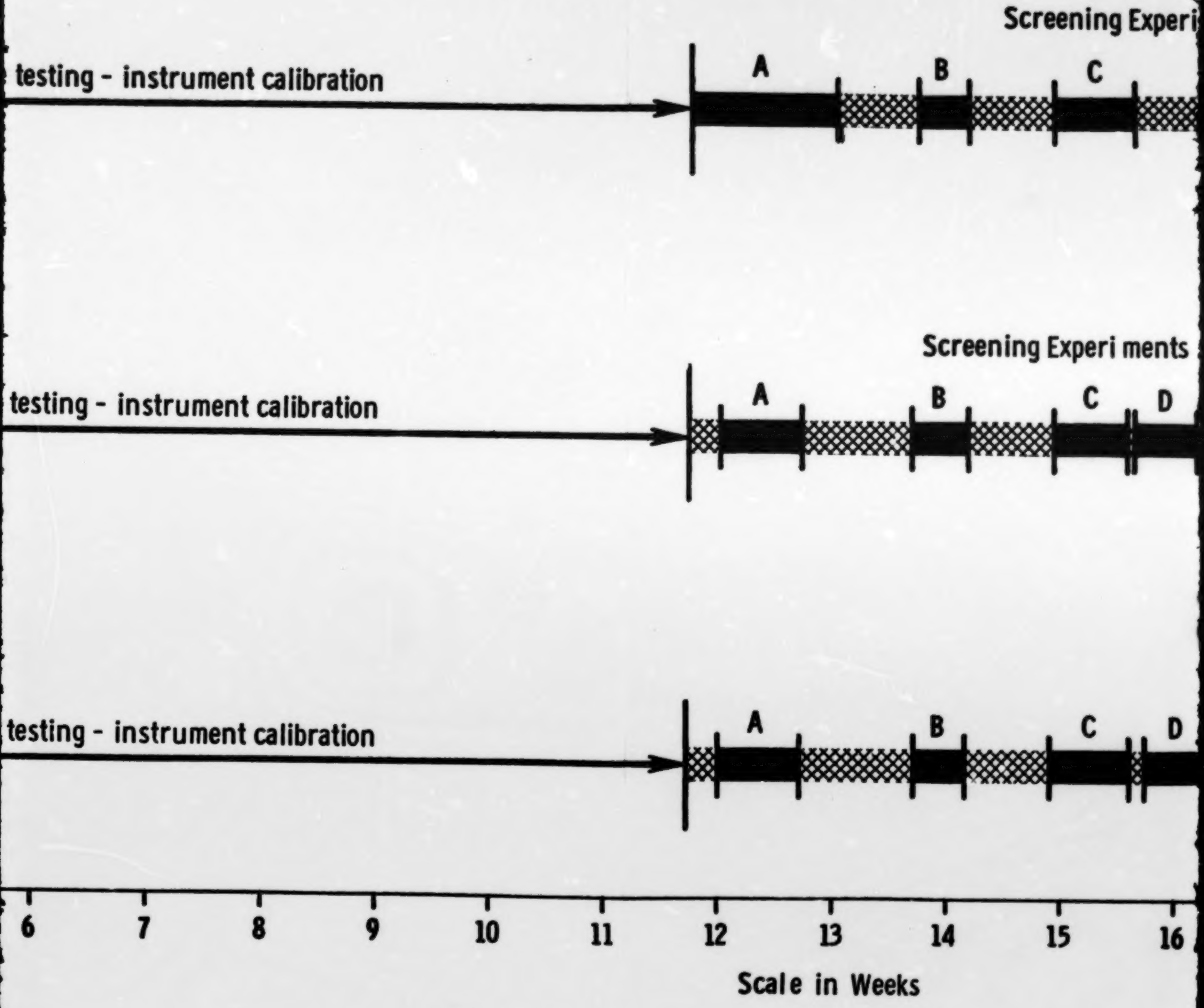
- Checkout of all equipment, piping, and wiring
- Isolated testing of equipment
- Clean-out of equipment and piping
- Checkout of control and alarm systems
- Process start-up
- Operating testing
- Equipment break-in
- Testing of emergency procedures

After the facility has been started up and proper operation achieved, a period of performance testing and instrument calibration will be initiated. The two months estimated time required for testing and calibration include:

- Evaluation of facility performance in all operational modes
- Validation of techniques for changing operational modes


PLANT #100
22 days
start-up
60 days performance testing - instrum
PLANT #200
22 days
start-up
60 days performance testing - instrum
PLANT #300
22 days
start-up
60 days performance testing - instrum
0
1
2
3
4
5
6
7

A


Screening Experi
testing - instrument calibration
A
B
C
Screening Experi ments
testing - instrument calibration
A
B
C
D
testing - instrument calibration
A
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D
6
7
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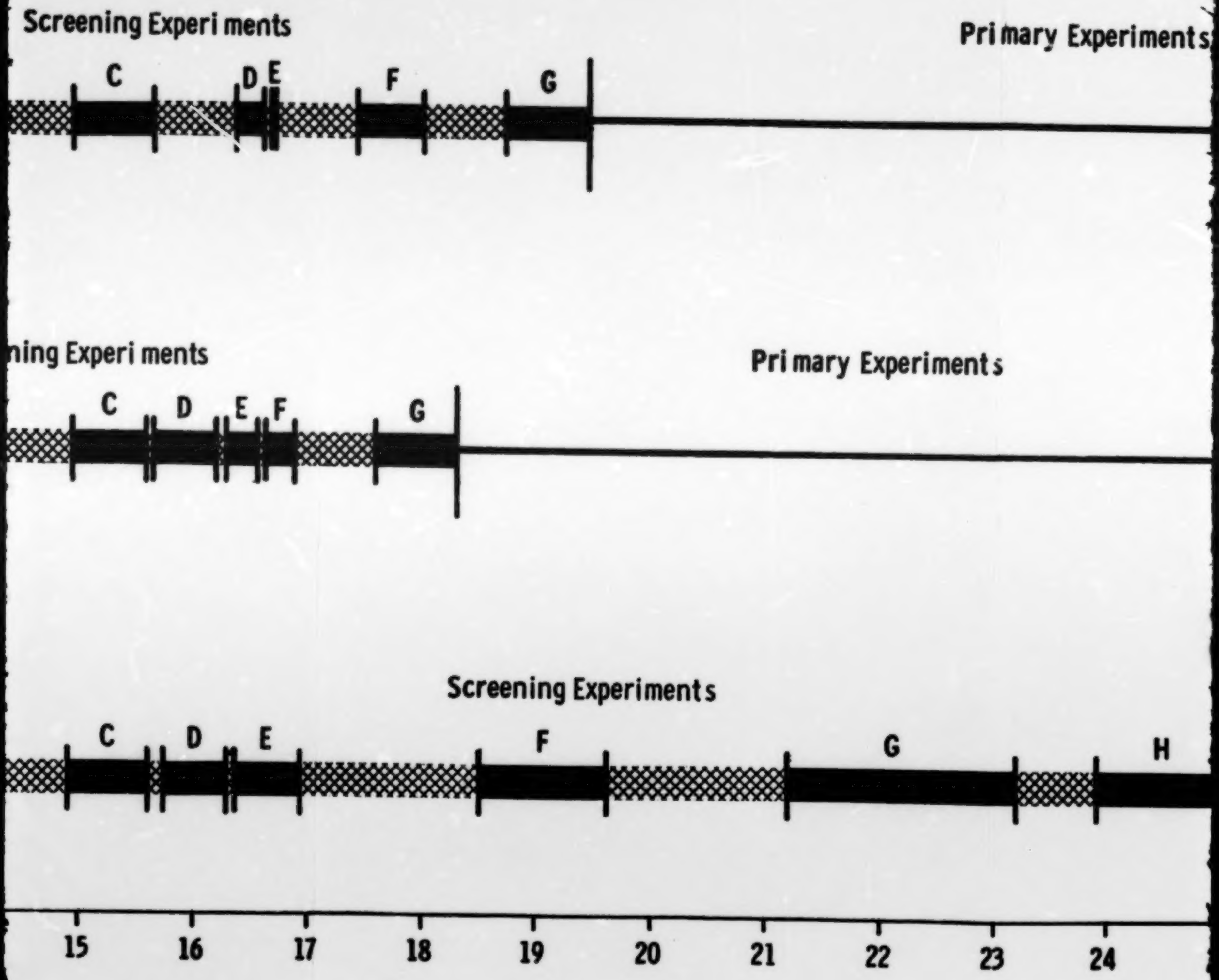
9
10
11
12
13
14
15
16
Scale in Weeks

B


Screening Experiments
Primary Experiments
C
D
E
F
G
ning Experiments
Primary Experiments
C
D
E
F
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Screening Experiments
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24

Figu

C

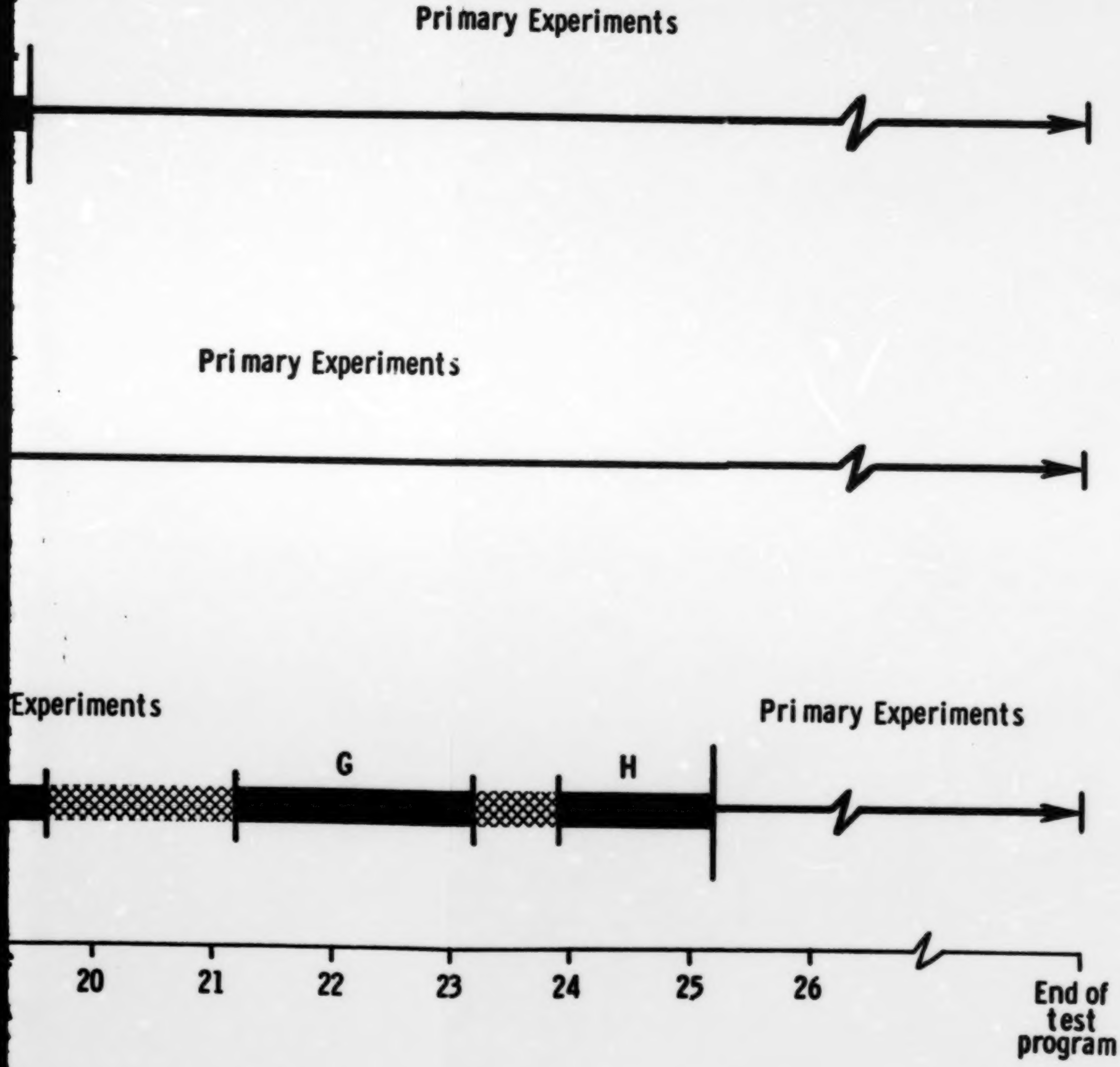


Figure 14-1. Preliminary Testing Schedule

D

- Accurate calibration of all instrumentation and data acquisition equipment
- Determination of instrument response rates

The screening experiments will have the following objectives:

- Evaluation of potential mechanical problems such as scrubber plugging
- Determine the effect of temperature on scrubber operation
- Establish material balance accuracy
- Establish and verify procedure for data reduction and as correlation
- Allow identification of principal variables and comparison of operational modes

14.9 COST OF PHASE III - TEST PROGRAM

In order to arrive at a realistic cost of running the test program, the material and service requirements have been assessed and an organization chart developed as a basis for estimating labor cost.

The material and services were calculated on a 50-percent average load-factor basis, with the assumption that preparation and downtimes will be interspersed evenly with actual running time. The organization chart, presented in Figure 14-2, was developed on the assumption that the evaluation of the test run, optimization of the variables, and overall technical management of Phase III will be accomplished in the home office of the contracting engineering firm. It was also based on the assumption that all the readings will be recorded on magnetic or punched tape and sent to the home office for evaluation. In case strip chart recorders are applied, additional personnel would be needed to handle and collect the charts in the field and to evaluate them in the office. The added personnel are not shown on the organization chart.

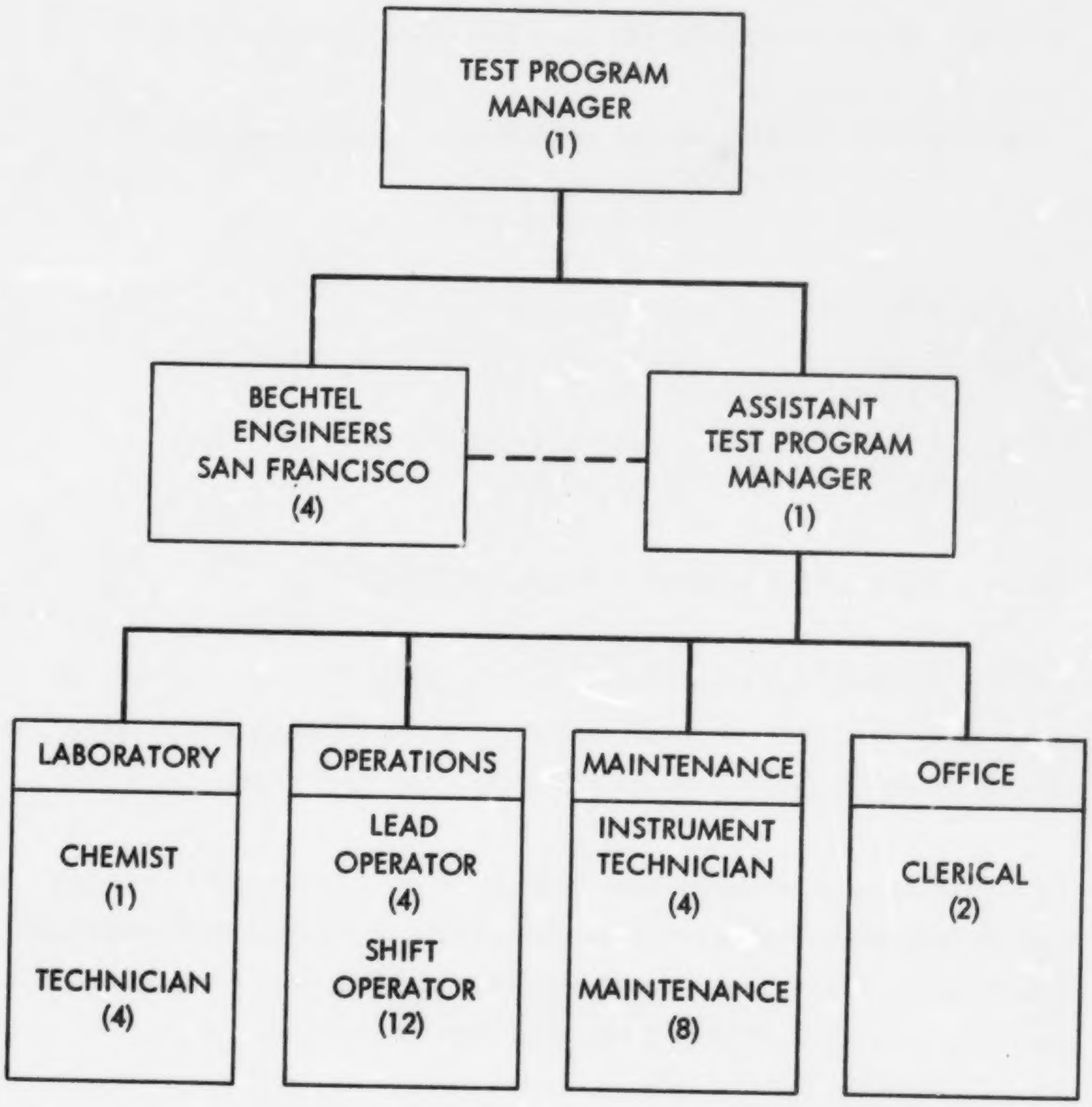

TEST PROGRAM
MANAGER
(1)
BECHTEL
ENGINEERS
SAN FRANCISCO
(4)
ASSISTANT
TEST PROGRAM
MANAGER
(1)
LABORATORY
CHEMIST
(1)
TECHNICIAN
(4)
OPERATIONS
LEAD
OPERATOR
(4)
SHIFT
OPERATOR
(12)
MAINTENANCE
INSTRUMENT
TECHNICIAN
(4)
MAINTENANCE
(8)
OFFICE
CLERICAL
(2)

Figure 14-2 Test Program Organization

The manpower requirement has been established on the basis that around-the-clock running of the experiments is foreseen. For immediate chemical analysis, a laboratory technician is kept on duty around the clock.

The duration of the test program is uncertain at this stage of engineering, since the time requirement of the primary experiments depends on the results of the screening experiments. For the purpose of the cost estimate, a 16-month period was planned for the test program. This requirement, however, may change after the results of the screening experiments are in.

Excluded from the cost estimate are:

- Insurance on the facility, since it is assumed that it will be government-insured
- Spare parts for the test equipment
- Major alterations of the test equipment which cannot be handled by the test personnel
- Major maintenance work exceeding the capacity of the test personnel

The estimate is presented in Table 14-15.

Table 14-15

COST OF TEST PROGRAM

Chemicals	Limestone	$ 303,000
	Miscellaneous	8,000
	Total	$ 311,000
Utilities	Steam	$ 51,000
	Natural Gas	56,800
	Water	20,600
	Electricity	46,000
	Coal	34,500
	Total	$ 209,000
Personnel	Operations	$ 450,000
	Bechtel Engineering	160,000
	Test Manager	45,000
	Asst. Test Manager	33,600
	Maintenance	346,000
	Laboratory	106,000
	Clerical	25,000
	Computer	10,000
	Total	$1,175,600
Misc.	Supplies, etc.	$ 20,000
	Waste Disposal	87,000
	Total	$ 107,000
	Subtotal	$1,802,600
	Contingency	360,300
	Fee	151,100
	Total	$2,314,000

Section 15

COST ESTIMATE

A summary cost estimate of the Alkali-Scrubbing Test Facility, based on preliminary design, is presented in Table 15-1. The estimate is limited in scope to the work required to add the alkali-scrubbing test equipment and modify the existing Unit 1 of Detroit Edison's St. Clair Power Station. It includes the necessary permanent plant materials and equipment, installation labor, supervision, construction equipment and tools, etc., that are necessary for the construction of the facility. Labor pricing is as quoted in Engineering News Record for the Detroit Area and labor productivity is assumed equal to that forecast for other Bechtel projects in the area. Details of the cost estimate are presented in Table 17-8.

The estimate includes escalation for completion of construction in mid-1970. It reflects a 5-percent-per-year increase in materials, 11-percent-per-year in labor, and 8-percent-per-year in subcontracts. Start-up cost is also included. It is assumed that the Phase III test program can begin immediately after Phase II work is completed.

Items specifically excluded from the estimate are:

- Modification to the existing plant except as specified
- Client costs, including interest during construction, land, land rights, test runs, and operating supplies
- Performance testing and operation. (Start-up and preliminary operation are limited to demonstrating completion of construction.)

The cost of Phase II engineering includes the following:

- Detailed engineering in the disciplines of:

  Mechanical Engineering
  Process Engineering
  Electrical Engineering
  Structural Engineering
  Instrument Engineering

- Project management, including coordination among the field and engineering office, NAPCA, and Detroit Edison Company
- Preparation of specifications, bid evaluation, purchasing and expediting, and cost control
- Further definition of the test program and preparation of test manuals and procedures, including computer codes for test evaluation and optimization

Table 15-1

SUMMARY OF COST ESTIMATE

Field Costs	Earthwork and Piling	$ 94,000
	Concrete	101,000
	Structural Steel and Miscellaneous Metal	51,000
	Filter Building	26,000
	Ductwork	238,000
	Additive Handling Equipment	144,000
	Flue Gas Equipment	702,000
	Sludge Handling Equipment	531,000
	Maintenance Equipment	44,000
	Piping	525,000
	Electrical	484,000
	Instrumentation	603,000
	Start-Up, Equipment and Systems Check-Out without Gas Flow	52,000
		$3,595,000
Other Costs	Engineering	$ 663,000
	Home Office	187,000
	Contingency	445,000
	Fee	255,000
	Escalation	205,000
		$1,755,000
Total Estimated Project Cost		$5,350,000

Section 16

SITE RESTORATION

The National Air Pollution Control Administration first expected that, after the test program was completed, the scrubbers and related equipment would be retained by the power company and utilized for air pollution abatement on Unit 1. This arrangement could have been promoted by sizing the experimental equipment so that it could pass the full Unit 1 flue-gas flow. At an early stage of engineering, however, it became clear that sizing the test equipment to treat the full flue-gas flow of the boiler would place undue financial burden on the project — considering that scrubber systems not proving satisfactory during the testing would not be accepted by Detroit Edison and would have to be removed.

In order to reduce the cost of test equipment, an agreement was reached with NAPCA that only one-half of the Unit 1 flue gas would be scrubbed. The other half, bypassing the scrubbers, would pass through the existing precipitators, induced-draft fans, and stack. With only one-half of the flue gas passing through the scrubbers, Detroit Edison sees no value in retaining the SO_2-removal equipment, even if all three scrubbers were to prove successful. Although Detroit Edison will retain an option to have first call on any equipment or facility installed for the test program, complete removal of all test-facility equipment and installations must be planned for. Preliminary discussions with Detroit Edison indicate that the concrete substructure supporting the scrubber systems can be left in place, but that foundations protruding above grade level will have to be removed.

It is possible, particularly if one or more of the scrubber systems proves to be successful in removing SO_2 and particulates, that Detroit Edison will decide to install flue gas scrubbers on Unit 1. Should they so decide, parts of the additive handling equipment, such as the limestone hopper, the Redler conveyor, the gravimetric feeder, and the bunker partition walls might be retained, even though the experimental scrubbers and their auxiliary equipment would be removed. It is also possible that part of the waste handling system, such as the clarifiers, the vacuum filter, and the centrifuge might be retained by Detroit Edison. While such arrangements are at this point only speculative, they would benefit both the government and Detroit Edison and should be included as an option in the contract to be entered into with Detroit Edison.

In order to reduce restoration costs, an evaluation of possible salvage value of the installed equipment was made, based on the following salvage rates:

- Structural steel tanks and ductwork, $0.03 per lb
- Equipment subject to caustic, 20 percent of original cost
- Equipment not subject to caustic, 30 percent of original cost
- Piping, $0.03 per lb or $1.00 per linear foot
- Valves, 30 percent of original cost
- Conduit and wire, not salvageable
- Instrument piping and tubing, 10 percent of original cost

A budget cost estimate has been prepared for site restoration, a summary of which is shown in Table 16-1. The estimated restoration cost is $600,000. Details of this estimate are presented in Table 17-9.

Table 16-1

SUMMARY OF SITE RESTORATION COST ESTIMATE

Field Costs	Main Distribution Duct	$ 31,000
	Flue Gas System	249,000
	Clarifiers and Related Equipment	270,000
	Filter Building Equipment	36,000
	Filter Building	14,000
	Additive Handling System	30,000
	Control Room Instrumentation	3,000
	Test Equipment	9,000
		$ 642,000
Material Salvage		($ 400,000)
Other Costs	Engineering	---
	Home Office Costs	28,000
	Contingency	130,000
	Fee	40,000
	Escalation	160,000
		$ 358,000
Total Estimated Site Restoration Cost		$ 600,000

Section 17

LOWER COST FACILITIES (PHASE IA)

Detailed capital cost estimates for the treatment facility as described in Section 3 were higher than preliminary estimates had indicated, possibly making necessary a curtailment in the test program. The extension to the Phase I study reported here was to develop the preliminary design for a facility that met the basic NAPCA program requirements but required a lower capital investment.

Rough capital, operating, and restoration cost estimates were prepared for four alternative process schemes selected jointly by Bechtel and the NAPCA. In agreement with the NAPCA, Bechtel selected the most promising of these schemes and prepared capital, operating, and restoration cost estimates to the same accuracy and depth as the basic design of Phase I.

17.1 DESCRIPTION OF DESIGN ALTERNATIVES

The process design alternatives represented various degrees of equipment elimination to reduce capital cost requirements. Units of equipment included in each of the alternatives are listed in Table 17-1, with the Phase-I-design equipment indicated for comparison.

Table 17-1

EQUIPMENT UNITS INCLUDED IN PHASE I AND ALTERNATIVE DESIGNS

Type of Equipment	Number of Equipment Units				
	Phase I	Alt. 1	Alt. 2	Alt. 3	Alt. 4
Scrubbers	3+1	3	2	3	1
Clarifiers	3	2	2	1	1
Filters	3+1	2	2	1	1
Fans	3	2	1	1	1
Stacks	3	1	1	1	1

Phase I design calls for three parallel scrubber systems in order to have the same flue gas composition and limestone additive composition for each scrubber type. In addition, an additional set of scrubber internals gave an opportunity for a fourth scrubber evaluation. A centrifuge was planned for comparison with the vacuum filters. Alternative I would connect two of the three scrubbers in parallel to a single flue-gas duct, followed by a single waste system. One of these scrubbers would then be operated at a time. The third, separate, scrubber would be operated simultaneously with either of the first two. Alternative 2 would have two complete scrubber-effluent trains with common reheat. Alternative 3 would connect three scrubbers in parallel to a single flue-gas duct and single effluent system. Only one scrubber would be operated at a time. Alternative 4 would consist of one complete scrubber train.

All four alternatives would employ a gas-fired reheater. A centrifuge would be included in Alternative 2 in order to compare its operation with that of the vacuum filter. Instrumentation and data reduction facilities would be the same as for the Phase I design. Limestone-addition facilities, too, would remain the same, since they are a function of the coal firing rate and not of scrubber operation.

Process flow diagrams for the four alternative systems are presented in Figures 17-1 through 17-4. The numbers in diamonds, ◇n , refer to the material-balance summaries presented on pages 11-5, 11-6, and 11-7.

17.2 EVALUATION OF DESIGN ALTERNATIVES

In evaluating the modified process schemes, the major program objectives must be considered. These are (1) to study the SO_2 removal process on a sufficiently large scale to generate reliable data for evaluating process problems, potentials, and economics, (2) to evaluate the effect of reaction and process variables, (3) to investigate scrubber differences, and (4) to develop process economics and full scale design. Table 17-3 shows the major and minor program objectives that are met by the Phase I design and each of the alternative designs.

Alternative 1 meets all objectives except development and evaluation of different full-scale reheater designs, evaluation of a centrifuge, and the determination of effects of different inlet-gas temperatures. As shown in Table 17-2, Alternative 1 would require 21 months to complete the

Table 17-2

TIME REQUIRED FOR PHASE I AND ALTERNATIVE TEST PROGRAMS
(months)

Program Phase	Time Required				
	Phase I	Alt. 1	Alt. 2	Alt. 3	Alt. 4
Start-up	2	2	2	2	2
Calibration	2	2	2	2	2
Screening Experiment	2	4	2	6	2
Primary Experiments	10	13	10	15	10
	16	21	16	25	16

Note: The test program is based on a 50-percent operating factor.

Table 17-3

MAJOR AND MINOR PROGRAM OBJECTIVES MET BY PHASE I AND ALTERNATIVE DESIGNS

Objectives	Objectives Met by Each Alternative				
	Phase I	Alt. 1	Alt. 2	Alt. 3	Alt. 4
Evaluate Alkali Scrubbing for Large-Scale SO_2 Removal	●	●	●	●	●
Evaluate the Effect of Reaction and Process Variables	●	●	●	●	●
Investigate Scrubber Differences	●	●	●	●	
Investigate the Effect of Different Additives	●	●	●	●	●
Develop Full-Scale Design	●	●	●	●	●
Develop Full-Scale Process Economics	●	●	●	●	●
Evaluate NO_x Reduction	●	●	●	●	●
Develop Full-Scale Reheater Design	●				
Operate Two Scrubbers Simultaneously	●	●	●		
Evaluate Centrifuge	●				
Provide Filter Back-Up	●				
Determine the Effects of Different Inlet-Gas Temperatures	●				
Evaluate Scrubber Inlet Design	●	●	●	●	

test program as compared to 16 months for the Phase I design. Alternative 2 meets the same objectives as Alternative 1 except it can evaluate only two types of scrubbers; it would require 16 months to complete the test program. Alternative 3 has the major limitation of not being able to evaluate more than one scrubber on the same flue-gas feed and limestone additive. This could cause variations in the data collected and make the correlation of data more difficult. Alternative 3 would require 25 months (the longest of the four alternatives) to complete the test program. Alternative 4 is limited to evaluating only one type of scrubber, which would be a major limitation of the test program. It would require 16 months to complete the test program.

17.3 CAPITAL COST ESTIMATES

Capital cost estimates for the four alternative designs were developed from the Phase I estimate by making allowance for the differences in design scope. Allowances for reduced bulk-material items occasioned by the reduction in capital expenditures were made on a percentage basis. Table 17-8 at the end of this section presents a comparison of the estimated capital costs of the Phase I design and the four alternative designs. These costs can be summarized as follows:

	Phase I	Alt. 1	Alt. 2	Alt. 3	Alt. 4
Capital Cost ($ million)	5.35	4.42	4.15	3.56	2.79
Savings over Phase I	----	0.93	1.20	1.79	2.56

All capital estimates are limited to the work required to add alkali-scrubbing test equipment and make other necessary modifications to Boiler 1. They include permanent plant materials and equipment, installation labor, supervision, construction equipment and tools, etc., as are necessary.

Escalation was based on scheduled completion of the unit in 1970 and reflects a five percent per year increase in material costs, eleven percent per year increase in labor costs, and eight percent per year increase in subcontract costs. Labor pricing is as quoted in Engineering News Record for the Detroit area and labor productivity is assumed equal to that forecast for other Bechtel projects in the area. Estimates for individual pieces of equipment were based on quotes received from vendors. Bulk items, such as piping and electrical equipment, were estimated from conceptual drawings.

Alternative 4, with the lowest capital cost estimate, was felt to limit the test program too severely since it would enable only one scrubber to be evaluated as to feasibility and efficiency. Alternative 2 was chosen by the NAPCA and Bechtel as the preferred alternative since, with minor modifications, it would enable two scrubbers and their auxiliary equipment to be evaluated simultaneously with identical feed-gas and limestone additives. These modifications are (1) to install a centrifuge in place of one of the filters and add the necessary piping to enable either scrubber to be used with either a centrifuge or a filter and (2) to add an additional gas reheater and induced-draft fan so that both scrubbing trains can be operated more efficiently. Alternative 2 will afford the same length of test program, 16 months, as would the Phase I design.

The Phase I drawings and equipment lists were altered to reflect the Alternative 2 changes and deletions. The drawings, presented at the end of this section, are related as indicated in Table 17-4. Modifications to the Phase I equipment list are presented in Table 17-7 after the drawings. (The original, Phase-I-design, equipment list is presented in Appendix A.) The capital cost estimate for Alternative 2 was developed to the accuracy and depth of the original, Phase I, design. This estimate is presented in summary form in Table 17-5 and in more detail in Table 17. 8.

Table 17-4

CORRELATION OF ALTERNATIVE 2 AND PHASE I DRAWINGS

Figure No. of Alternative 2 Drawing	Title	Figure No. of Corresponding Phase I Drawing
17-5	Process Piping and Instrumentation Diagram, Plant No. 100	3-5
17-6	Process Piping and Instrumentation Diagram, Plant No. 200	3-6
17-7	Flue Gas Instrumentation and Control Diagram	12-1
17-8	General Arrangement Plan, Precipitator Bypass and Scrubbers	3-8
17-9	General Arrangement, Scrubbers, Elevation C-C	3-9
17-10	General Arrangement, Scrubbers, Elevations D-D, E-E, and F-F	3-10
17-11	Precipitator Bypass Duct, Sections A-A and B-B	3-11
17-12	Plot Plan	3-1

Table 17-5

SUMMARY OF ALTERNATIVE 2 CAPITAL COST ESTIMATE

Field Costs	Earthwork and Piling	$ 69,000
	Concrete	85,000
	Structural Steel	41,000
	Filter Building	20,000
	Ductwork	184,000
	Additive Handling Equipment	145,000
	Flue Gas Equipment	375,000
	Sludge Handling	332,000
	Maintenance Equipment	44,000
	Piping	387,000
	Electrical	436,000
	Instrumentation	496,000
	Start-up	50,000
		$2,662,000
Other Costs	Engineering	$ 624,000
	Home Office	176,000
	Contingency	343,000
	Fee	197,000
	Escalation	148,000
		$1,488,000
Total Estimated Project Cost		$4,150,000

17.4 RESTORATION COST ESTIMATES

The estimates for removal of and rehabilitation after the alternative designs were factored from the Phase I estimate on the basis of reduction in pieces of equipment and percentage-reduction in bulk materials.

Material salvage estimates were based on the following rates:

- Structural steel tanks and ductwork, \$0.03 per lb.
- Equipment subject to caustic, 20 percent of original cost
- Equipment not subject to caustic, 30 percent of original cost
- Piping, \$0.03 per lb. or \$1.00 per linear foot
- Valves, 30 percent of original cost
- Conduit and wire, not salvageable
- Instrument piping and tubing, 10 percent of original cost

Table 17-9 compares the restoration costs for the Phase I design and the four alternative designs. These costs vary from \$600,000 for Phase I to \$350,000 for Alternative 4.

17.5 OPERATING COST ESTIMATES

The cost calculations for operating the test program Phase I design and the four alternative designs were based on the schedules shown in Table 17-2 and the test facility staff shown in Table 17-6. Operating cost totals, including chemicals, utilities, labor, waste disposal, contingency, and fee are given at the top of page 17-11. The operating costs are tabulated in Table 17-10.

Table 17-6

COMPARISON OF PHASE I AND ALTERNATIVE DESIGN TEST FACILITY STAFFS

Position Title	Number of Personnel				
	Phase I	Alt. 1	Alt. 2	Alt. 3	Alt. 4
Test Manager	1	1	1	1	1
Assistant Manager	1	1	1	1	1
Bechtel Engineers	4	4	4	4	4
Lead Operators	4	4	4	4	4
Shift Operators	12	8	8	4	4
Maintenance	12	11	11	10	10
Clerical	2	2	2	2	2
Chemist	1	1	1	1	1
Lab Technicians	4	4	4	4	4
Total	41	36	36	31	31

	Phase I	Alt. 1	Alt. 2	Alt. 3	Alt. 4
Total Operating Cost ($million)	2.31	2.79	2.14	2.90	1.86

Alternative 2, which was chosen by the NAPCA and Bechtel for more detailed evaluation, has the lowest operating cost for a process scheme where two scrubbers can be evaluated simultaneously. It saves $170,000 over the Phase I design.

The operating costs for the Phase I facility were calculated as follows, based on a 50-percent operating factor. Operating costs for the four alternative facilities were calculated similarly.

- Chemicals

  Limestone: 358 tons per day @ $3.50 per ton
  Miscellaneous Chemicals: $1,000 per operating month

- Utilities

  Coal: 860 tons per operating month @ $5.00 per ton
  Steam: 17,500 pounds per hour @ $0.50 per 1000 pounds
  Natural Gas: 22,000 standard cubic feet per hour @ $0.45 per 1000 standard cubic feet
  Electricity: 2000 kilowatts per hour @ $0.004 per kilowatt-hour
  Water: 120 gallons per hour @ $0.50 per 1000 gallons

- Personnel

  1 Test Program Manager @ $20,000 per year
  1 Assistant Test Program Manager @ $15,000 per year

  Plus 22.5% fringe benefits plus 40% overhead

  4 Bechtel Engineers in San Francisco @ $13,000 per year each

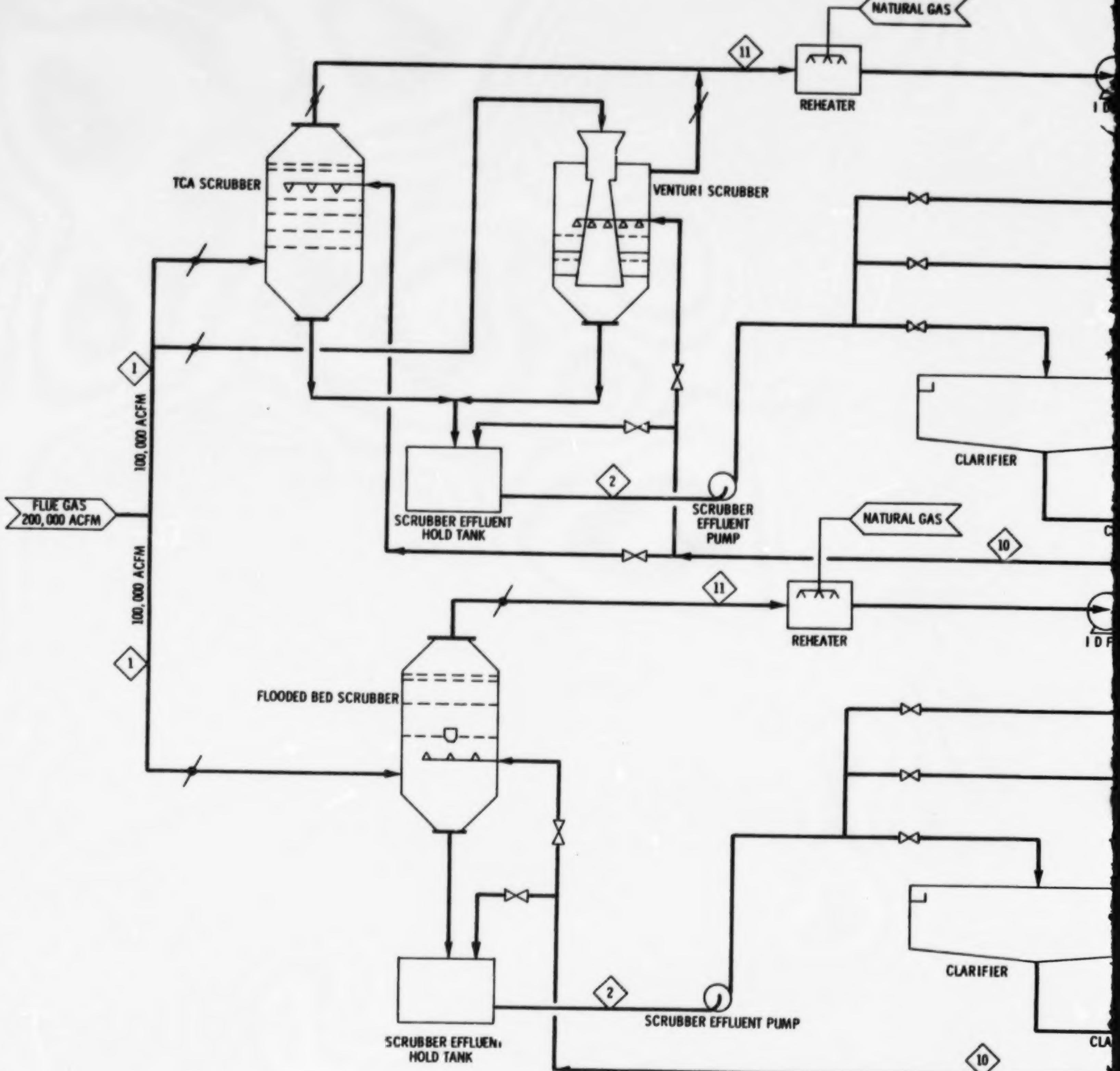
  Plus 22.5% fringe benefits plus 90% overhead

  4 Lead Operators @ $8.00 per hour each
  12 Maintenance Personnel, including tractor operators, instrument technicians, and general mechanics, @ $7.39 per hour each

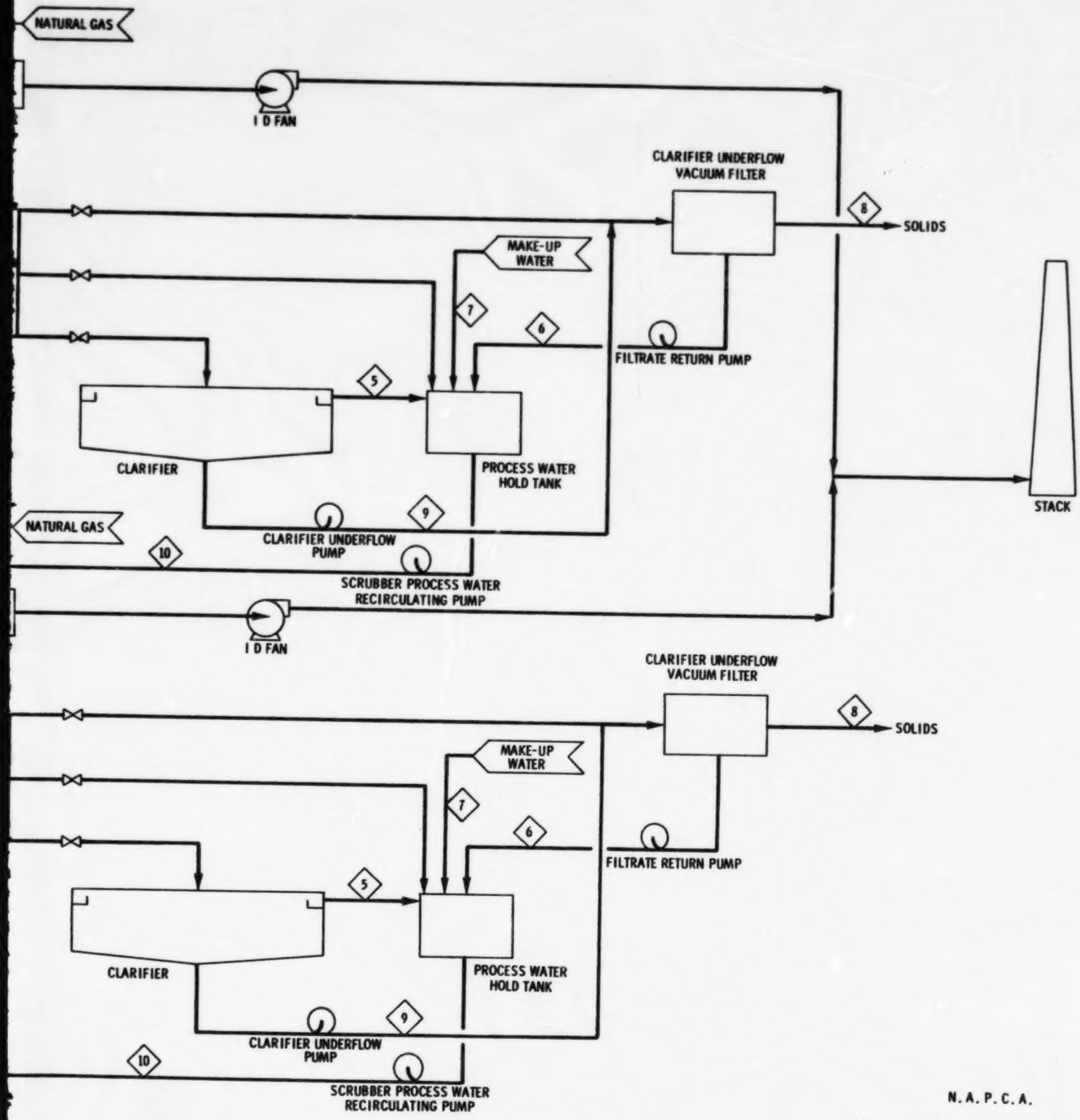
12 Shift Operators @ $6.94 per hour each
1 Chemist @ $6.25 per hour
4 Laboratory Technicians @ $5.20 per hour each
2 Clerks @ $3.25 per hour each

Plus 40% overhead (fringe benefits included in hourly rates)

- Computer: 15 hours @ $650 per hour
- Travel, Supplies: $400 per day
- Waste Disposal: 25 tons per hour @ $0.60 per ton


NATURAL GAS
11
REHEATER
I D
TCA SCRUBBER
VENTURI SCRUBBER
1
100,000 ACFM
FLUE GAS 200,000 ACFM
2
SCRUBBER EFFLUENT HOLD TANK
SCRUBBER EFFLUENT PUMP
CLARIFIER
C
NATURAL GAS
10
100,000 ACFM
11
REHEATER
I D F
1
FLOODED BED SCRUBBER
CLARIFIER
2
SCRUBBER EFFLUENT PUMP
CLA
SCRUBBER EFFLUEN, HOLD TANK
10

A


NATURAL GAS
I D FAN
CLARIFIER UNDERFLOW VACUUM FILTER
8
SOLIDS
MAKE-UP WATER
7
6
FILTRATE RETURN PUMP
5
CLARIFIER
PROCESS WATER HOLD TANK
STACK
NATURAL GAS
9
CLARIFIER UNDERFLOW PUMP
10
SCRUBBER PROCESS WATER RECIRCULATING PUMP
I D FAN
CLARIFIER UNDERFLOW VACUUM FILTER
8
SOLIDS
MAKE-UP WATER
7
6
FILTRATE RETURN PUMP
5
CLARIFIER
PROCESS WATER HOLD TANK
9
CLARIFIER UNDERFLOW PUMP
10
SCRUBBER PROCESS WATER RECIRCULATING PUMP

◇ NOTE: Refer to Material Balance Summary for Line Identification.

N. A. P. C. A.

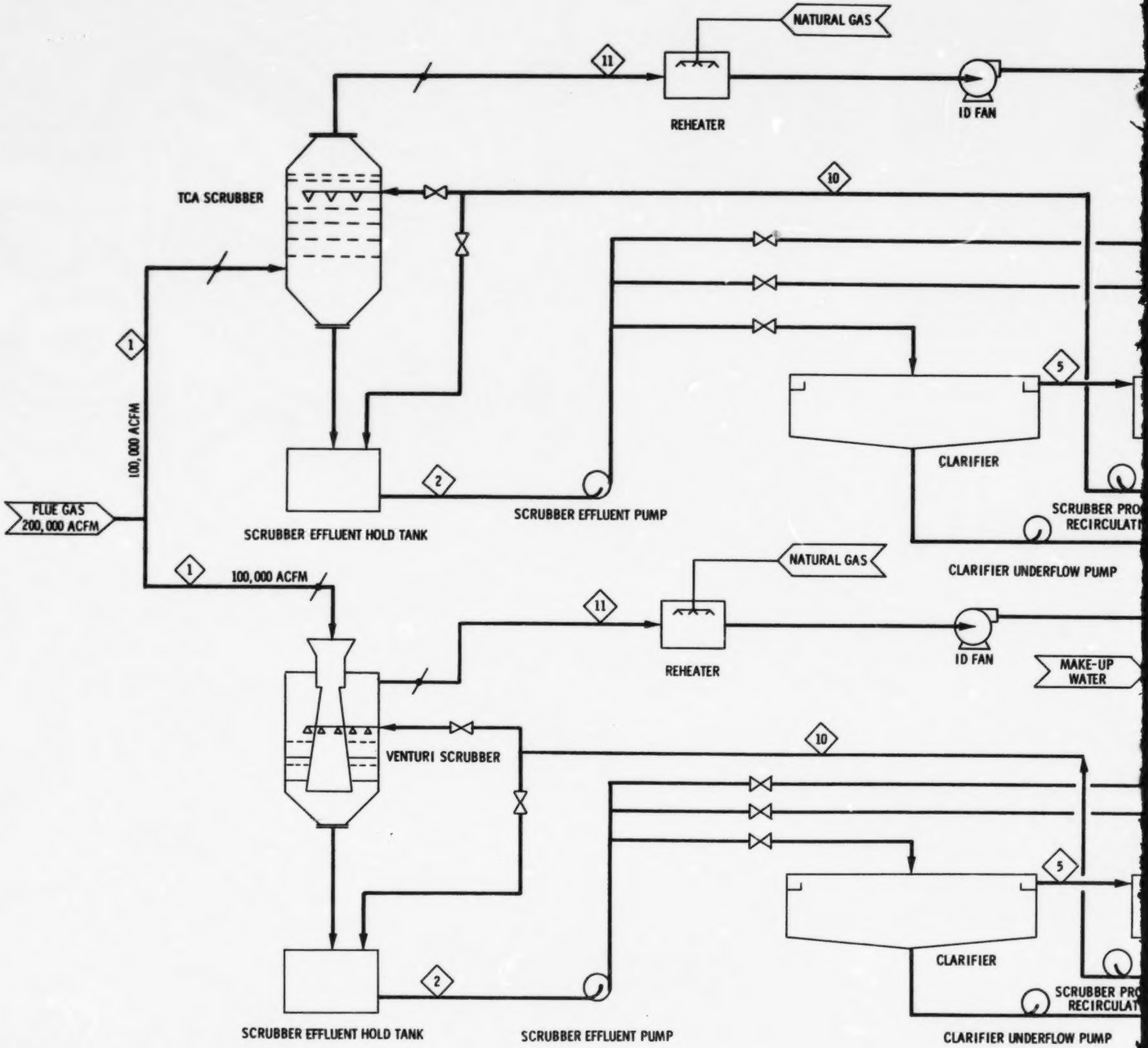
ALKALI SCRUBBING TEST FACILITY

PHASE 1A

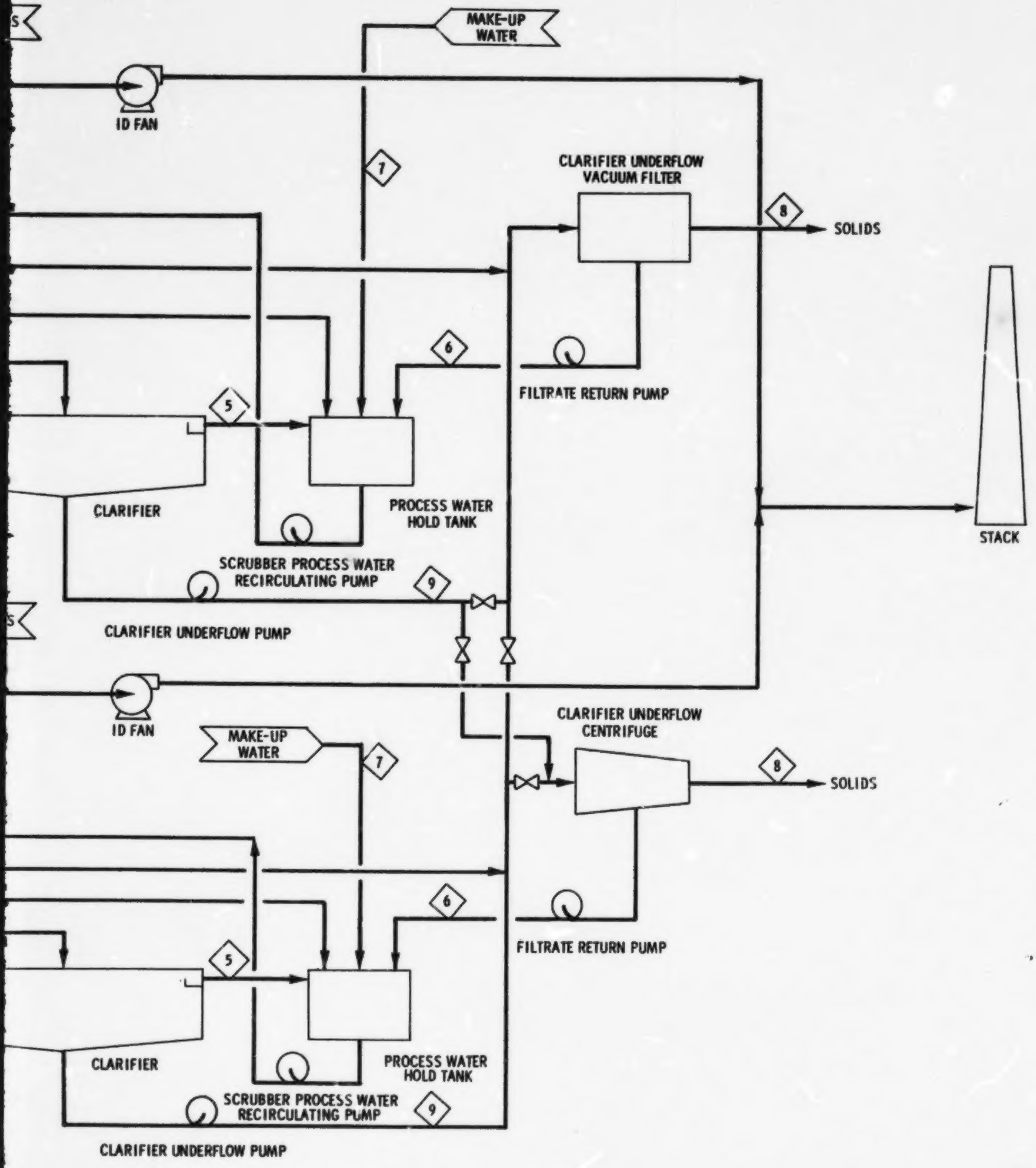
PROCESS FLOW DIAGRAM, ALTERNATIVE 1

April 1969 Figure 17 - 1

B


NATURAL GAS
11
REHEATER
ID FAN
TCA SCRUBBER
10
1
100,000 ACFM
5
CLARIFIER
2
SCRUBBER EFFLUENT HOLD TANK
SCRUBBER EFFLUENT PUMP
SCRUBBER PRO
RECIRCULATN
FLUE GAS
200,000 ACFM
CLARIFIER UNDERFLOW PUMP
1
100,000 ACFM
NATURAL GAS
11
REHEATER
ID FAN
MAKE-UP
WATER
VENTURI SCRUBBER
10
5
CLARIFIER
2
SCRUBBER EFFLUENT HOLD TANK
SCRUBBER EFFLUENT PUMP
SCRUBBER PRO
RECIRCULAT
CLARIFIER UNDERFLOW PUMP

A


MAKE-UP WATER
ID FAN
7
CLARIFIER UNDERFLOW VACUUM FILTER
8
SOLIDS
6
FILTRATE RETURN PUMP
5
CLARIFIER
PROCESS WATER HOLD TANK
STACK
SCRUBBER PROCESS WATER RECIRCULATING PUMP
9
CLARIFIER UNDERFLOW PUMP
ID FAN
CLARIFIER UNDERFLOW CENTRIFUGE
MAKE-UP WATER
7
8
SOLIDS
6
FILTRATE RETURN PUMP
5
CLARIFIER
PROCESS WATER HOLD TANK
SCRUBBER PROCESS WATER RECIRCULATING PUMP
9
CLARIFIER UNDERFLOW PUMP

◇ NOTE: Refer to Material Balance Summary for Line Identification.

N. A. P. C. A.

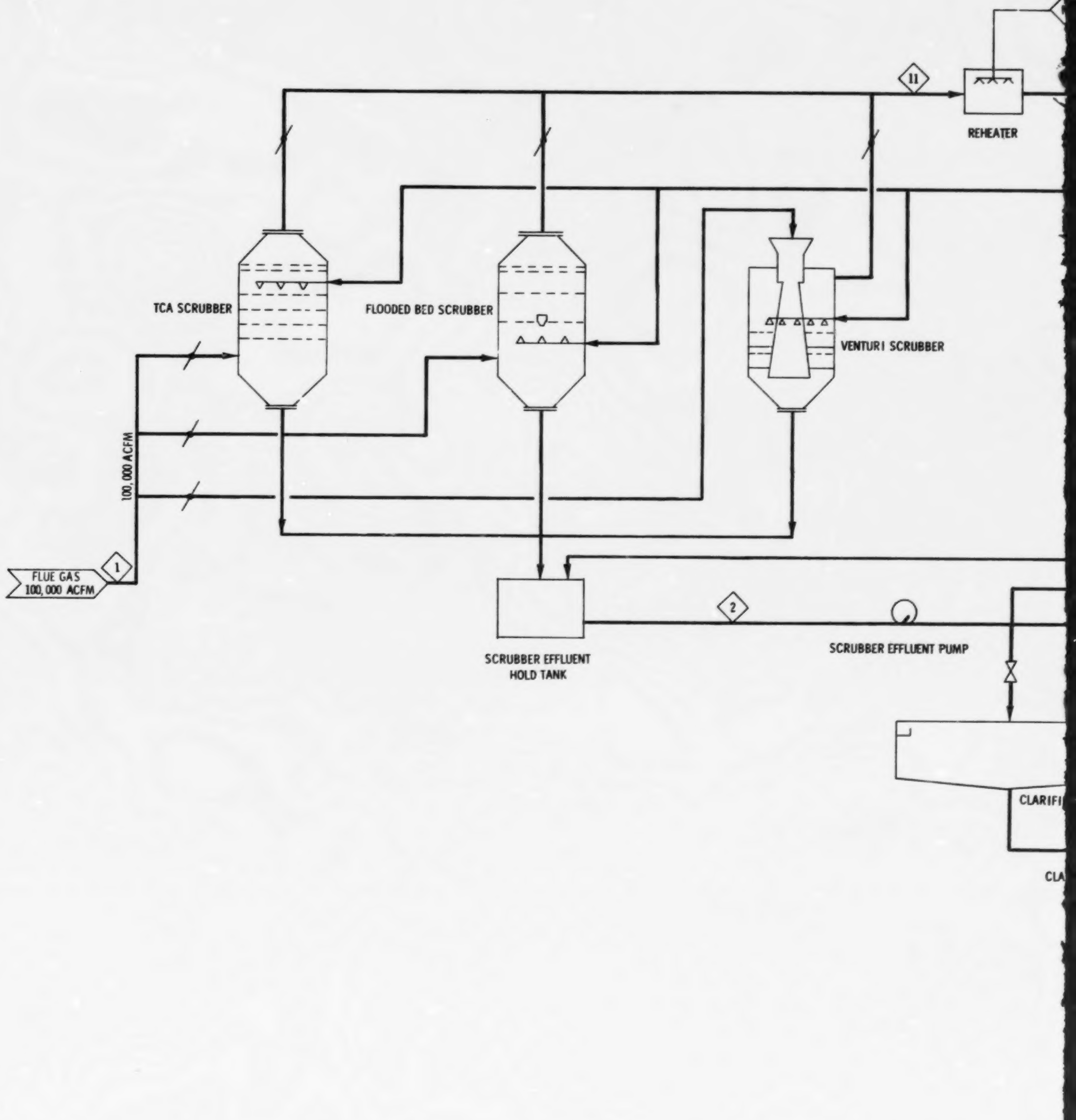
ALKALI SCRUBBING TEST FACILITY

PHASE 1A

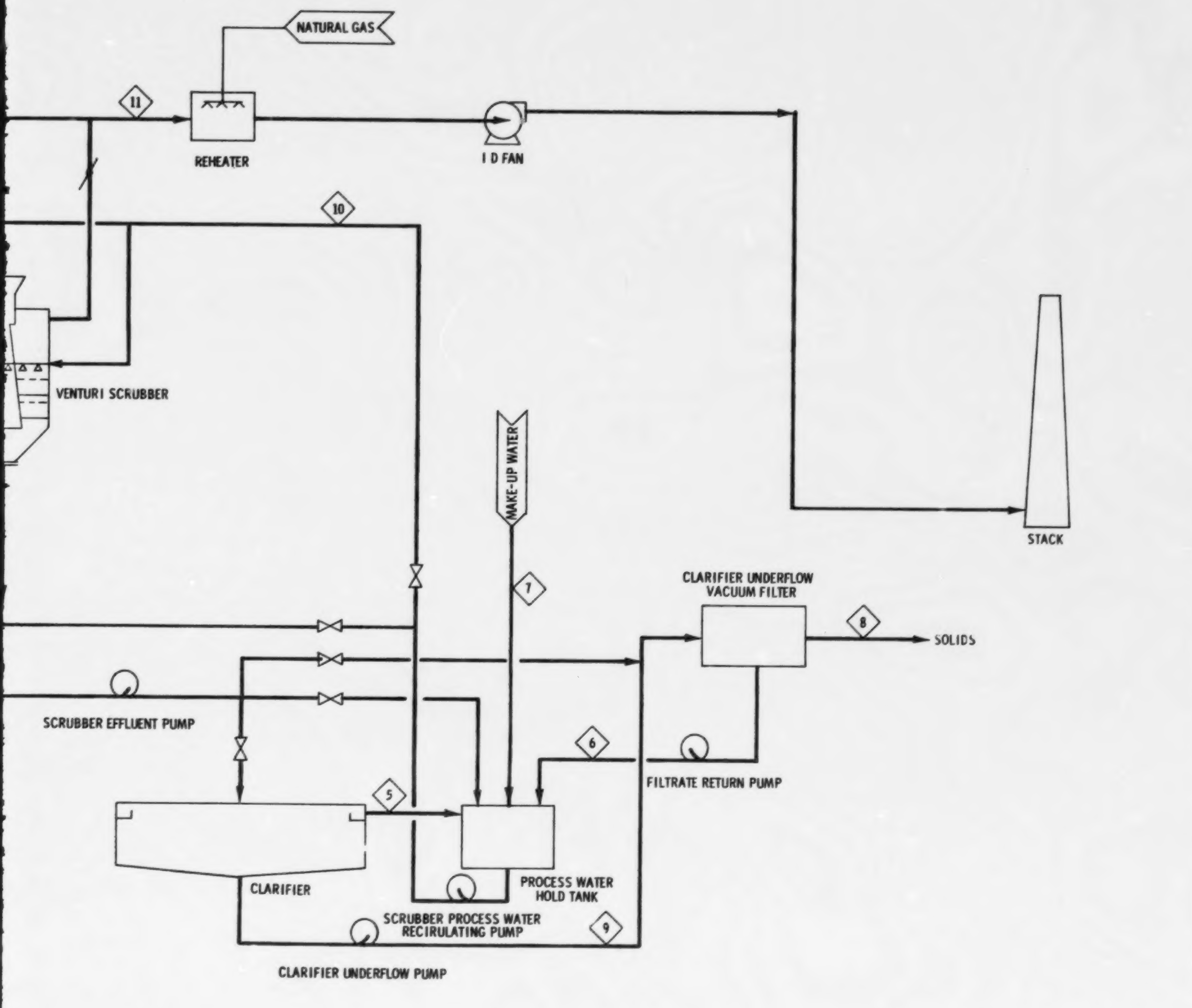
PROCESS FLOW DIAGRAM, ALTERNATIVE 2

April 1969 Figure 17 - 2

B


11
REHEATER
TCA SCRUBBER
FLOODED BED SCRUBBER
VENTURI SCRUBBER
100,000 ACFM
1
FLUE GAS
100,000 ACFM
2
SCRUBBER EFFLUENT HOLD TANK
SCRUBBER EFFLUENT PUMP
CLARIFI
CLA

A


NATURAL GAS
11
REHEATER
I D FAN
10
VENTURI SCRUBBER
MAKE-UP WATER
STACK
7
CLARIFIER UNDERFLOW
VACUUM FILTER
8
SOLIDS
SCRUBBER EFFLUENT PUMP
6
FILTRATE RETURN PUMP
5
CLARIFIER
PROCESS WATER
HOLD TANK
SCRUBBER PROCESS WATER
RECIRULATING PUMP
9
CLARIFIER UNDERFLOW PUMP

◇ NOTE: Refer to Material Balance Summary for Line Identification.

N. A. P. C. A.

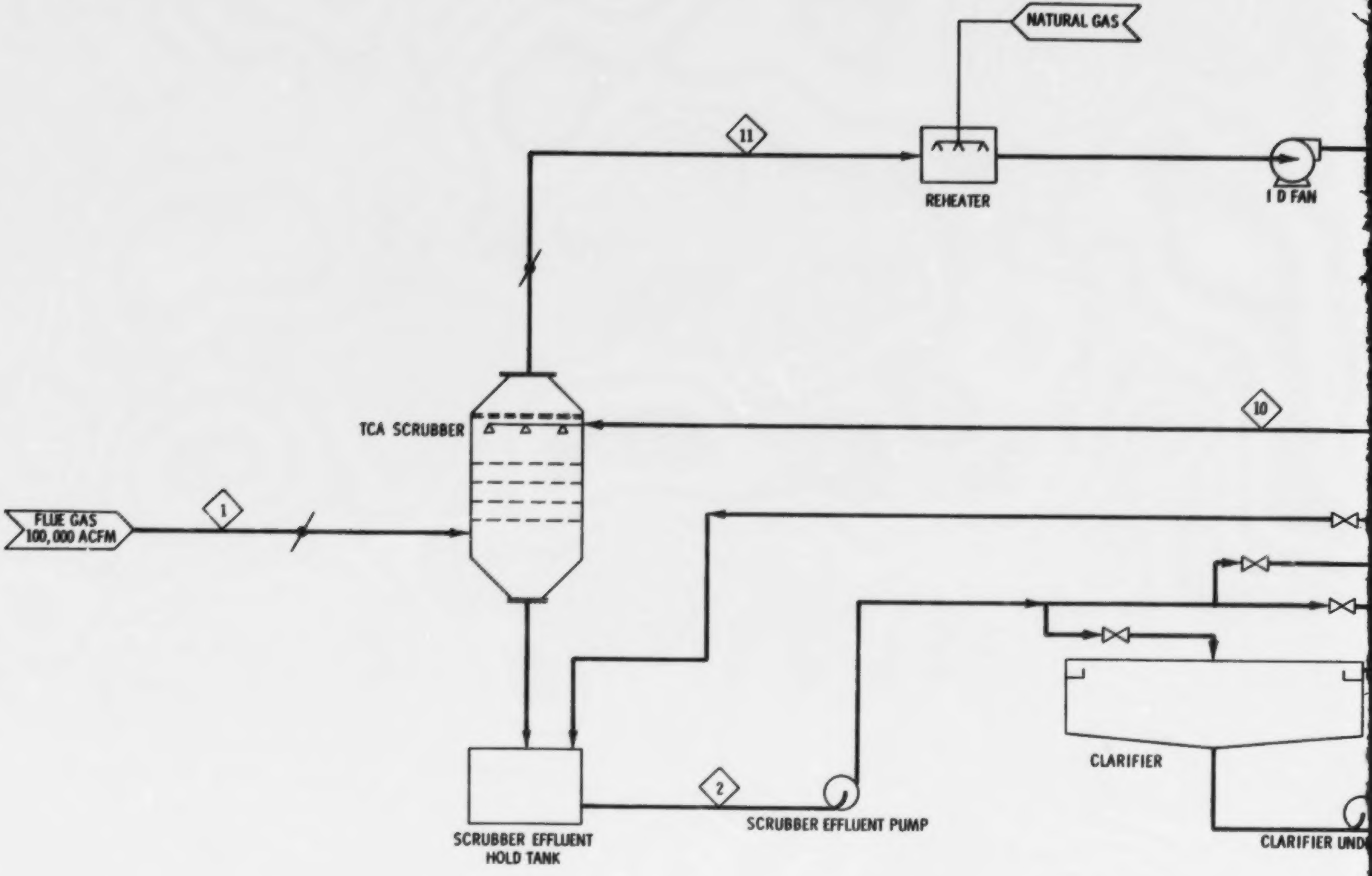
ALKALI SCRUBBING TEST FACILITY

PHASE 1A

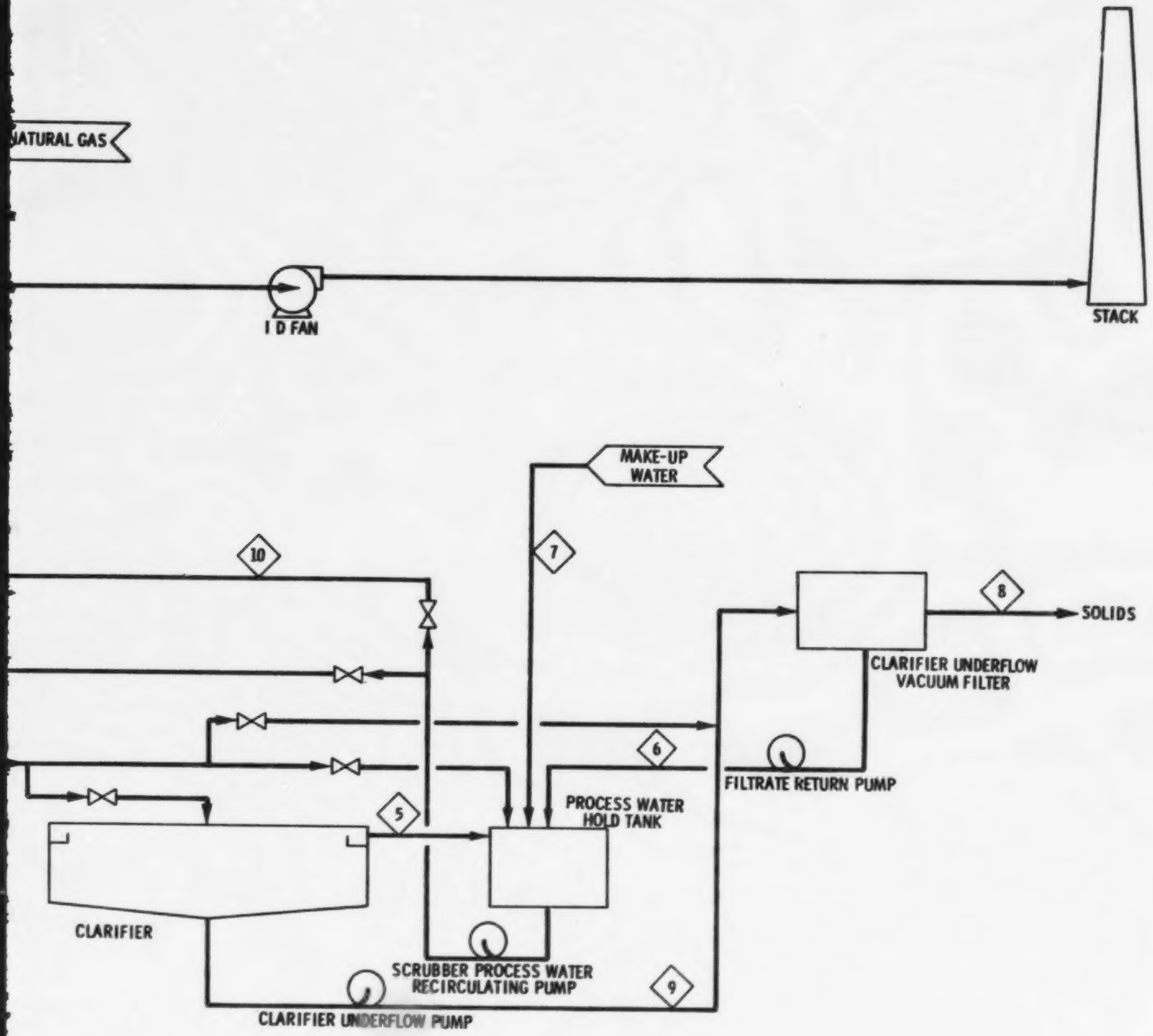
PROCESS FLOW DIAGRAM, ALTERNATIVE 3

April 1969 Figure 17 - 3

B


NATURAL GAS
11
REHEATER
I D FAN
TCA SCRUBBER
10
FLUE GAS
100,000 ACFM
1
CLARIFIER
2
SCRUBBER EFFLUENT PUMP
SCRUBBER EFFLUENT
HOLD TANK
CLARIFIER UND

A


NATURAL GAS
I D FAN
STACK
MAKE-UP WATER
10
7
8
SOLIDS
CLARIFIER UNDERFLOW VACUUM FILTER
6
FILTRATE RETURN PUMP
PROCESS WATER HOLD TANK
5
CLARIFIER
SCRUBBER PROCESS WATER RECIRCULATING PUMP
9
CLARIFIER UNDERFLOW PUMP

◇ NOTE: Refer to Material Balance Summary for Line Identification.

N. A. P. C. A.

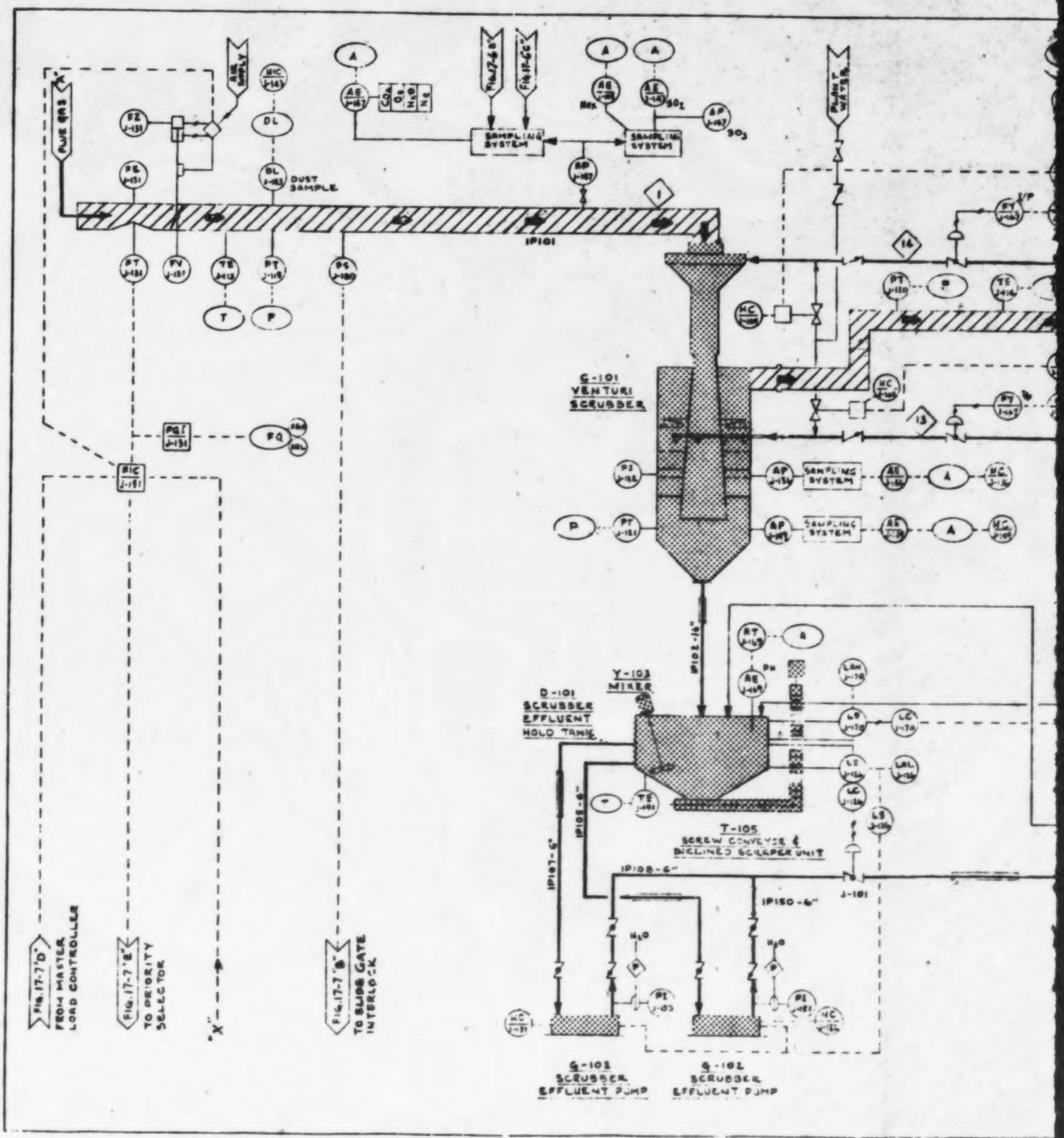
ALKALI SCRUBBING TEST FACILITY

PHASE 1A

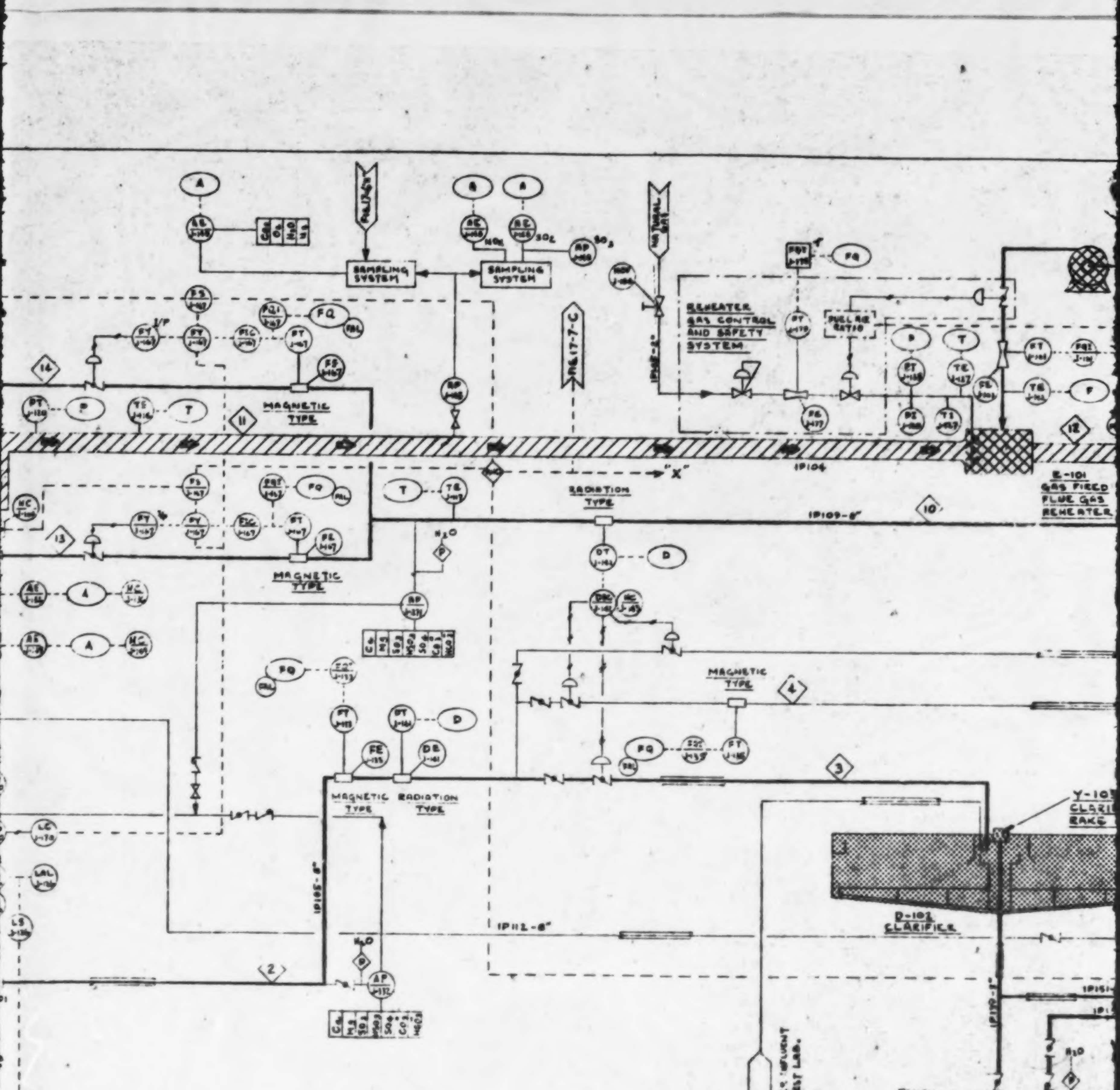
PROCESS FLOW DIAGRAM, ALTERNATIVE 4

April 1969 Figure 17 - 4

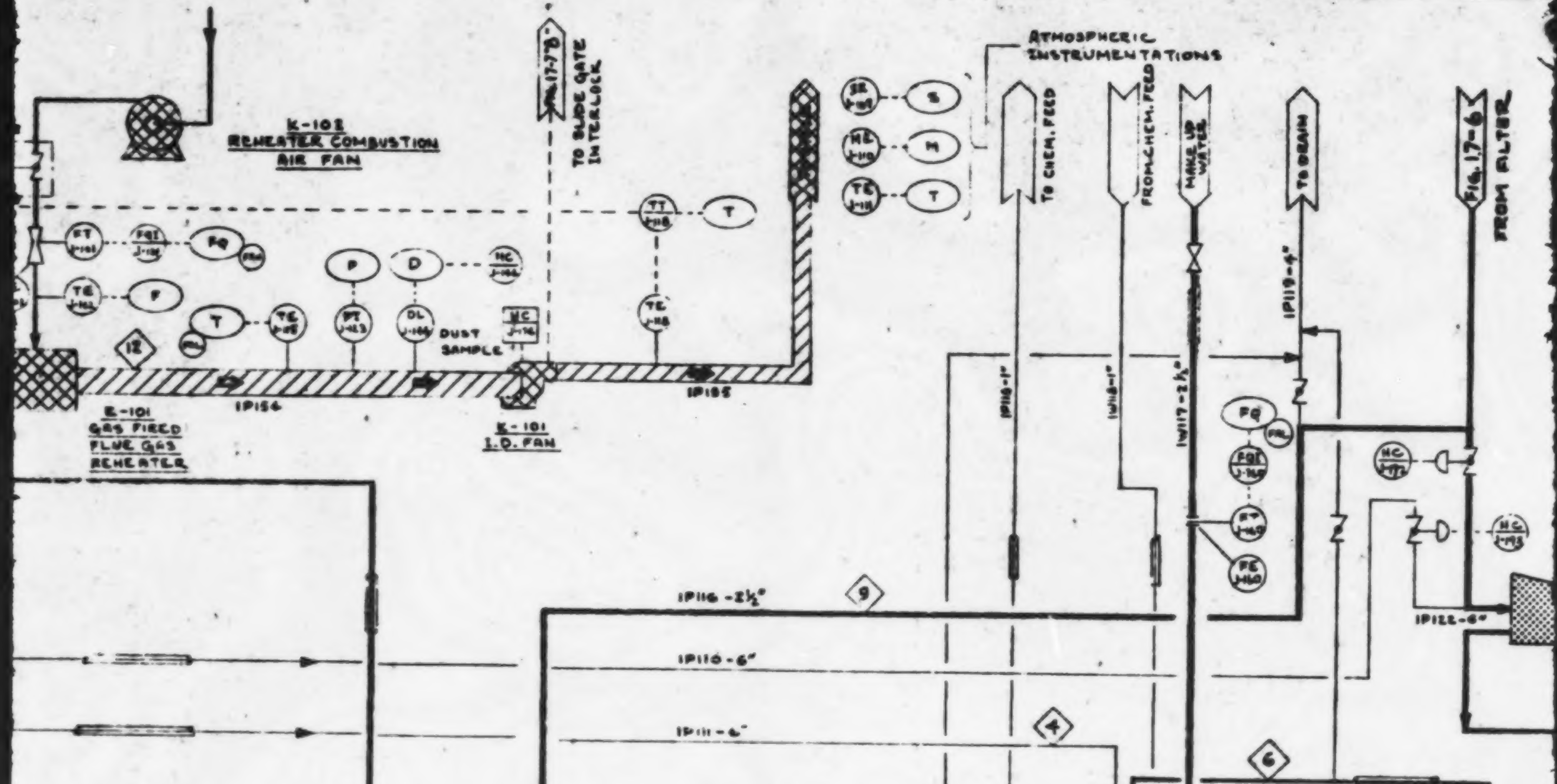
B


FLUE GAS
"X"
AIR SUPPLY
FZ J-131
FE J-131
PT J-131
FV J-131
TE J-113
PT J-119
PS J-180
T
P
HIC J-143
DL
DL J-183
DUST SAMPLE
A
AE J-147
CO2
O2
H2O
N2
Fig.17-6"B"
Fig.17-6"C"
SAMPLING SYSTEM
SAMPLING SYSTEM
AE J-181
AE J-141
SO2
SO3
AP J-147
NOx
AP J-167
1
1P101
PLANT WATER
14
13
PT J-120
TE J-116
HC J-105
HC J-106
PY J-167
G-101
VENTURI SCRUBBER
PS J-122
PT J-121
AP J-134
AP J-182
AE J-134
HC J-134
HC J-109
FQI J-131
FQ
FIC J-131
Fig.17-7"D"
FROM MASTER LOAD CONTROLLER
Fig.17-7"E"
TO PRIORITY SELECTOR
Fig.17-7"B"
TO SLIDE GATE INTERLOCK
1P102-16"
AT J-169
AE J-169
PH
Y-103
MIXER
D-101
SCRUBBER EFFLUENT HOLD TANK
TE J-181
LAH J-170
LT J-170
LC J-170
LS J-126
LAL J-126
LC J-126
LS J-126
T-105
SCREW CONVEYOR & INCLINED SCRAPER UNIT
1P107-6"
1P108-6"
1P150-6"
J-101
H2O
PI J-103
PI J-181
HC J-131
HC J-126
G-103
SCRUBBER EFFLUENT PUMP
G-102
SCRUBBER EFFLUENT PUMP

A


A
AE
SAMPLING SYSTEM
SAMPLING SYSTEM
NOx
SO2
AP
SO3
FE-17-7-C
NATURAL GAS
FS
PY
PQI
FQ
FIC
FT
FE
I/P
14
PT
P
TE
T
11
MAGNETIC TYPE
REHEATER GAS CONTROL AND SAFETY SYSTEM
FUEL/AIR RATIO
PDT
PT
FE
PI
TI
12
IP104
"X"
E-101 GAS FIRED FLUE GAS REHEATER
HC
13
RADIATION TYPE
IP109-8"
10
H_2O
DT
D
DRC
MAGNETIC TYPE
4
3
MAGNETIC TYPE
RADIATION TYPE
DE
LC
LAL
LS
IP106-8"
IP112-8"
2
ΔP
Y-103 CLARIFIER RAKE
D-103 CLARIFIER
SCRUBBER INFLUENT FROM TEST LAB.
FLUSH WATER
IP151
G-103 CLARIFIER UNDERFLOW PUMP

B


K-102
REHEATER COMBUSTION AIR FAN
FIG. 17-7B
TO SLIDE GATE INTERLOCK
ATMOSPHERIC INSTRUMENTATIONS
TO CHEM. FEED
FROM CHEM. FEED
MAKE UP WATER
TO DRAIN
FIG. 17-6
FROM FILTER
FT J-101
FQI J-111
FQ
TE J-102
F
T
TE
PT J-103
DL J-104
P
D
HC J-106
HC J-116
DUST SAMPLE
TT J-118
TE J-118
T
SE
S
ME
M
TE
12
1P154
1P155
E-101
GAS FIRED FLUE GAS REHEATER
K-101
I.D. FAN
1P118-1"
1W118-1"
1W117-2½"
1P119-4"
FQ
FQI J-140
FT J-140
FE J-140
HC J-192
HC J-193
1P122-6"
1P116-2½"
9
1P110-6"
1P111-6"
4
6
Y-103
CLARIFIER RAKE & DRIVER
1P114-12"
5
Y-104
MIXER
D-103
PROCESS WATER HOLD TANK
AE
AT J-73
PH
A
LAH
LT J-139
LIC J-139
HC J-139
LS J-139
LO
FY J-139
AND
PS J-136
FT J-136
RC
RO
HC
1P113-8"
RC
RO
HC J-138
1P154-6"
1P151-2"
1P153-2"
1P130-3"
1P132-6"
1P136-6"
1P120-6"
1W121-6"
1P151-2"
FE J-157
FT J-137
FQI J-137
FQ
H₂O
P
PI J-135
PI J-136
PI J-137
HC J-137
FLUSH WATER
FIG. 17-6
TO FILTER
RINSE WATER
G-103
CLARIFIER UNDERFLOW PUMP
G-104
CLARIFIER UNDERFLOW PUMP
G-105
SCRUBBER PROCESS WATER RECIRCULATING PUMP
G-106
SCRUBBER PROCESS WATER RECIRCULATING PUMP
G-109
FILTRATE
PUMP

C

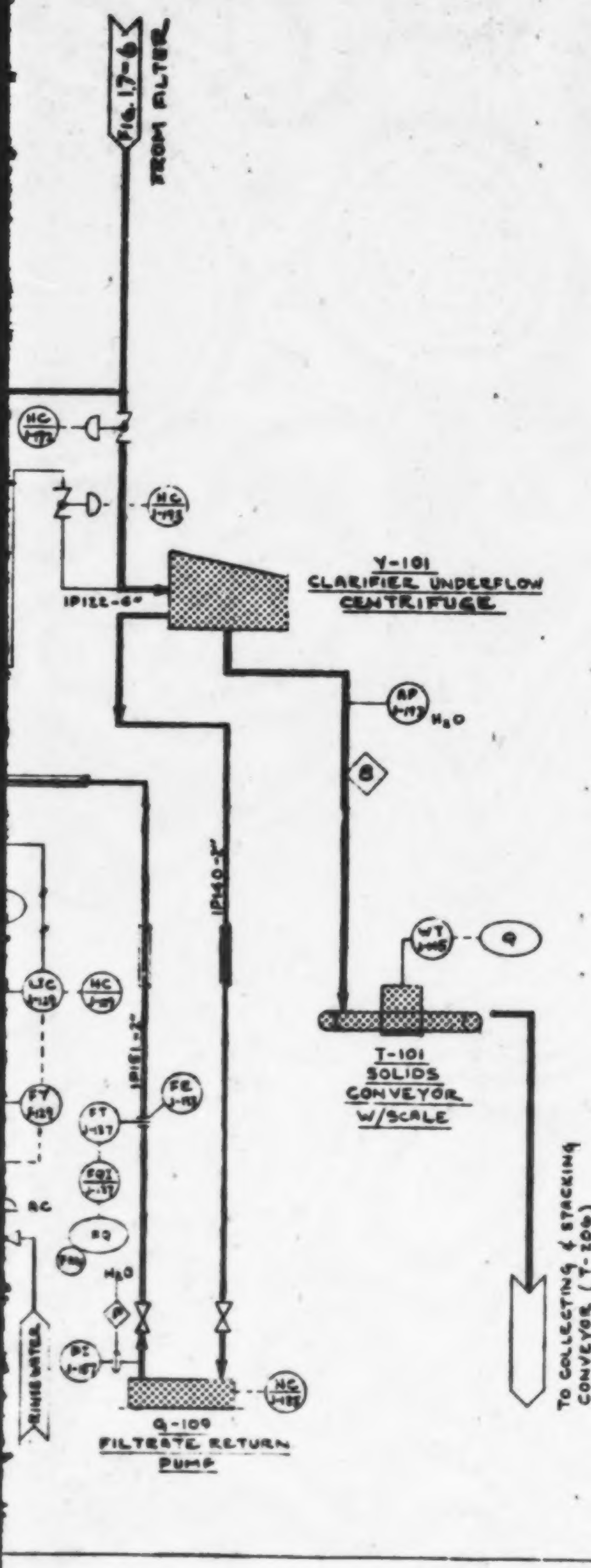


FIG. 17-6
FROM FILTER
HC 1-192
HC 1-193
1P122-6"
V-101
CLARIFIER UNDERFLOW
CENTRIFUGE
AP 1-197
H₂O
P
1P140-3"
1P161-3"
WT 1-195
Q
T-101
SOLIDS
CONVEYOR
W/SCALE
LIC 1-129
HC 1-129
FY 1-129
FT 1-187
FE 1-187
FQI 1-187
RC
RQ
H₂O
P
PI 1-187
RINSE WATER
HC 1-188
G-109
FILTRATE RETURN
PUMP
TO COLLECTING & STACKING
CONVEYOR (T-200)

NOTES.

1. ◇P = INDICATES PURGE POINT
2. AP = INDICATES SAMPLE POINT
3. FOR INSTRUMENTATION NUMBERING & IDENTIFICATION, REFERENCE APPENDIX E-1, E-2, E-3, E-4 & E-5
4. SYMBOLS BELOW CARRY THE IDENTIFICATION INDICATED

⊟ DEVICE LOCATED IN BOILER CONTROL ROOM

⊖ DEVICE LOCATED IN TEST FACILITY CONTROL CENTER

○ LOCAL MOUNTED DEVICES

▩ AQUEOUS EQUIPMENT

▨ FLUE GAS

▦ FLUE GAS EQUIPMENT

ALTERNATIVE 2

△			
△			
△	ISSUED FOR REPORT		2-5
	REVISIONS		

SCALE NONE | J. HING

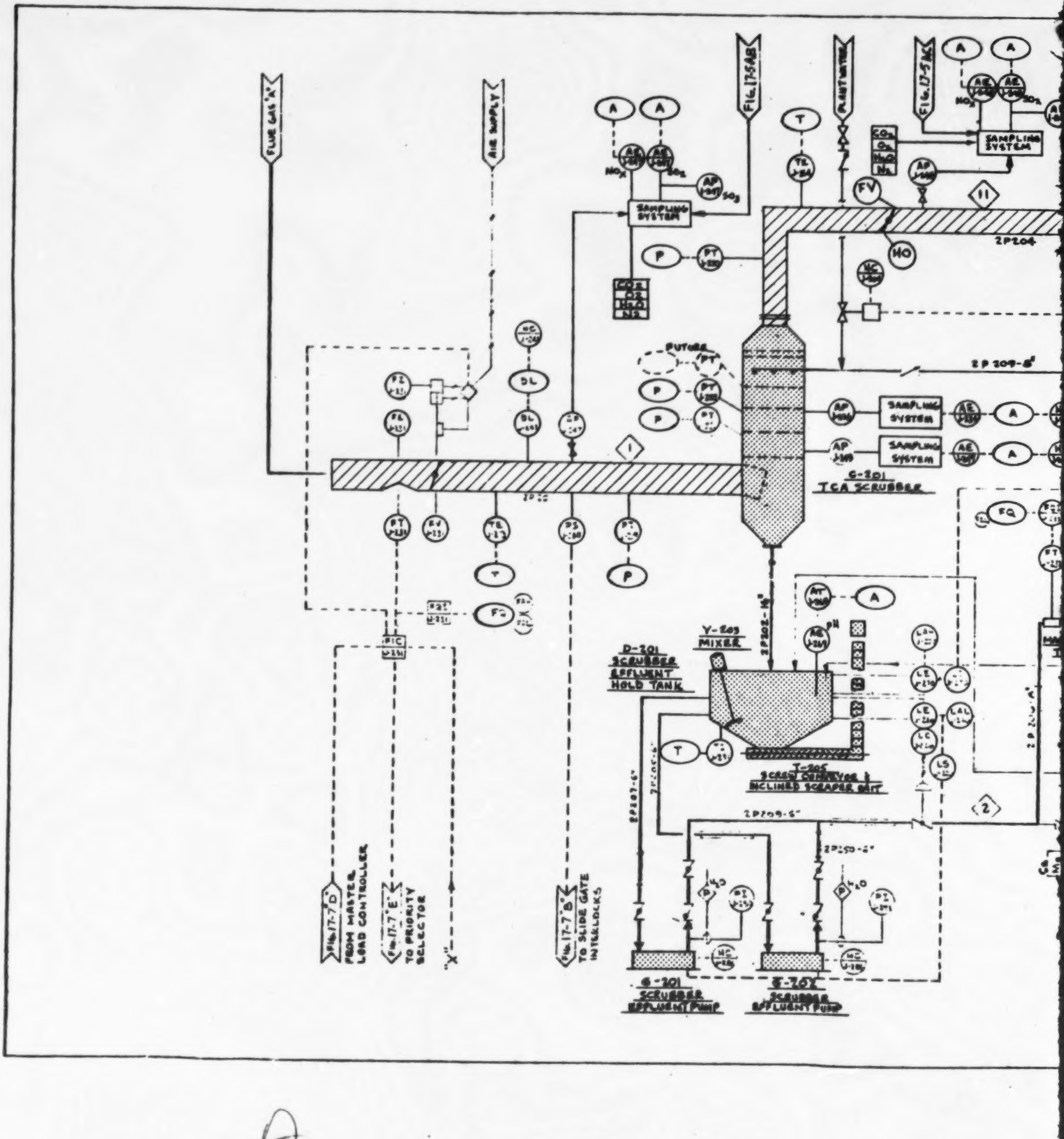
BECHTEL CORPORATION
SAN FRANCISCO

N. A. P. C. A
ALKALI SCRUBBING TEST FACILITY
DETOIT EDISON ST. CLAIR PLANT-MICHIGAN

PROCESS PIPING & INSTRUMENTATION DIAGRAM
PLANT NO. 100

BECHTEL	6955	FIGURE 17-5	0

D


FLUE GAS 'A'
AIR SUPPLY
FIG. 17-5AB
PLANT WATER
FIG. 17-5 BC
A
A
AE
AE
NOx
SO2
AP
SO3
SAMPLING SYSTEM
CO2
O2
H2O
N2
T
TE
FV
HO
11
2P204
P
PT
HC
FUTURE
PT
P
P
AP
SAMPLING SYSTEM
AE
A
AP
SAMPLING SYSTEM
AE
A
2P209-8"
G-201
TCA SCRUBBER
FZ
FE
DL
DL
1
PT
FV
TE
PS
PT
T
P
F
FQ
PT
FIC
Y-203
MIXER
D-201
SCRUBBER EFFLUENT HOLD TANK
2P202
AT
A
AE
pH
LA
LE
LE
LAL
LC
LS
T
T-205
SCREW CONVEYOR &
INCLINED SCRAPER UNIT
2P207-6"
2P209-5"
2P250-2"
2
H2O
PI
HC
G-201
SCRUBBER EFFLUENT PUMP
G-202
SCRUBBER EFFLUENT PUMP
FIG. 17-7 'D'
FROM MASTER LOAD CONTROLLER
FIG. 17-7 'E'
TO PRIORITY SELECTOR
"X"
FIG. 17-7 'B'
TO SLIDE GATE INTERLOCKS

A

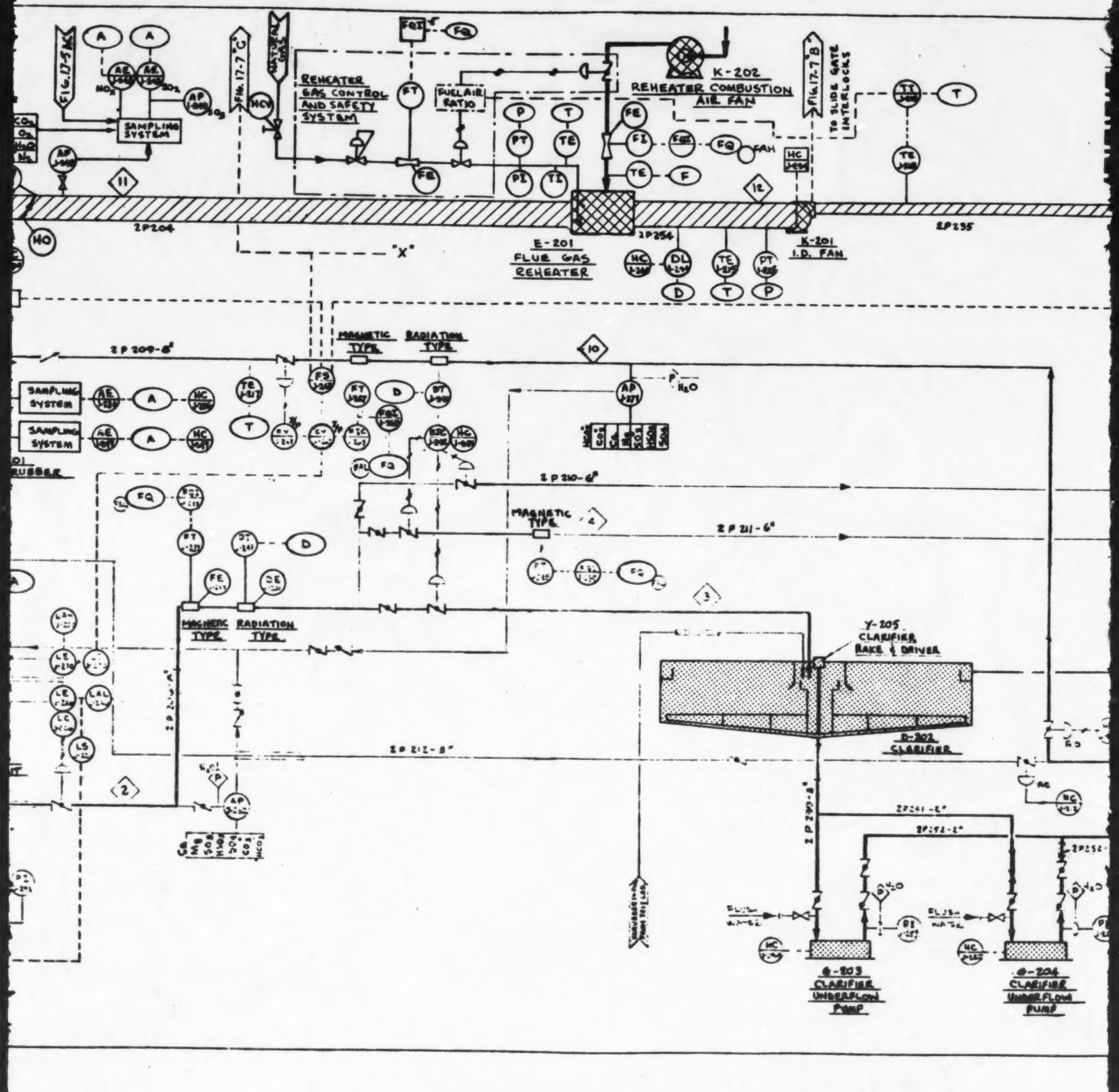
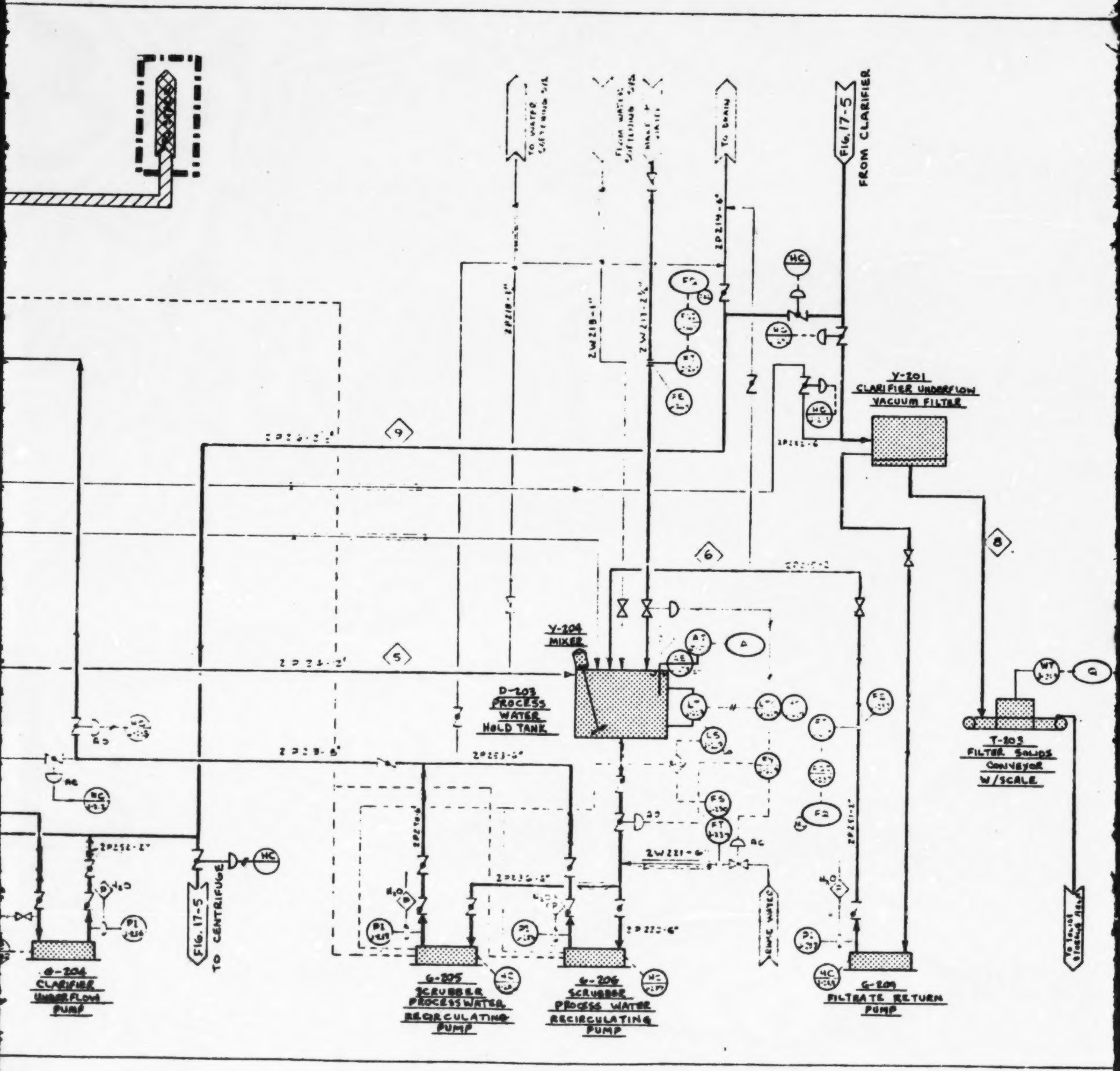
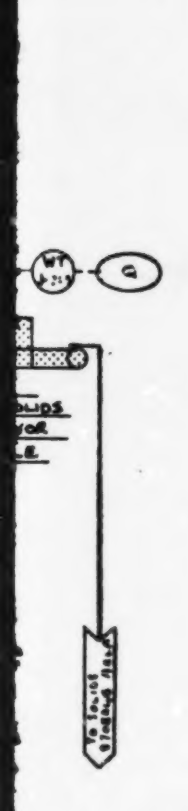


FIG. 17-5 "A"
FIG. 17-7 "C"
NATURAL GAS
FIG. 17-7 "B"
TO SLIDE GATE INTERLOCKS
SAMPLING SYSTEM
REHEATER GAS CONTROL AND SAFETY SYSTEM
FUEL/AIR RATIO
K-202
REHEATER COMBUSTION AIR FAN
E-201
FLUE GAS REHEATER
K-201
I.D. FAN
2P204
2P254
2P235
"X"
2P 209-8"
2P 210-6"
2P 211-6"
2P 212-8"
MAGNETIC TYPE
RADIATION TYPE
SAMPLING SYSTEM
SCRUBBER
Y-205
CLARIFIER RAKE & DRIVER
D-202
CLARIFIER
G-203
CLARIFIER UNDERFLOW PUMP
G-204
CLARIFIER UNDERFLOW PUMP
FLUSH WATER
2P241-2"
2P252-2"
11
12
10
4
3
2
A
FQ
FT
FE
FI
TE
TT
PT
DL
HC
AE
AP
HCV
T
P
D
F
FQS
FAH
H2O
CO2
O2
N2
NO2
SO2

B


TO WATER SOFTENING S/S
FROM WATER SOFTENING S/S
MAKE-UP WATER
TO DRAIN
FIG. 17-5
FROM CLARIFIER
2P218-1"
2W218-1"
2W217-2½"
2P214-6"
HC
FE
Y-201
CLARIFIER UNDERFLOW
VACUUM FILTER
2P252-6
9
6
8
5
2P253-2"
2P251-2"
Y-204
MIXER
D-203
PROCESS
WATER
HOLD TANK
AT
A
LS
FS
FT
F2
AC
WT
Q
T-203
FILTER SOLIDS
CONVEYOR
W/SCALE
TO SOLIDS STORAGE AREA
2P253-8"
2P253-6"
2P252-2"
2P256-2"
2P222-6"
2W221-6"
H2O
PI
HC
FIG. 17-5
TO CENTRIFUGE
RINSE WATER
G-204
CLARIFIER
UNDERFLOW
PUMP
G-205
SCRUBBER
PROCESS WATER
RECIRCULATING
PUMP
G-206
SCRUBBER
PROCESS WATER
RECIRCULATING
PUMP
G-209
FILTRATE RETURN
PUMP

C



INDICATES CHANGES, SEE EQUIPMENT LIST FOR ADDITIONAL INFORMATION.

▒ AQUEOUS EQUIPMENT

▨ FLUE GAS

▩ FLUE GAS EQUIPMENT

NOTE:
FOR GENERAL NOTES SEE FIGURE 3-5

ALTERNATIVE 2

△	
△	
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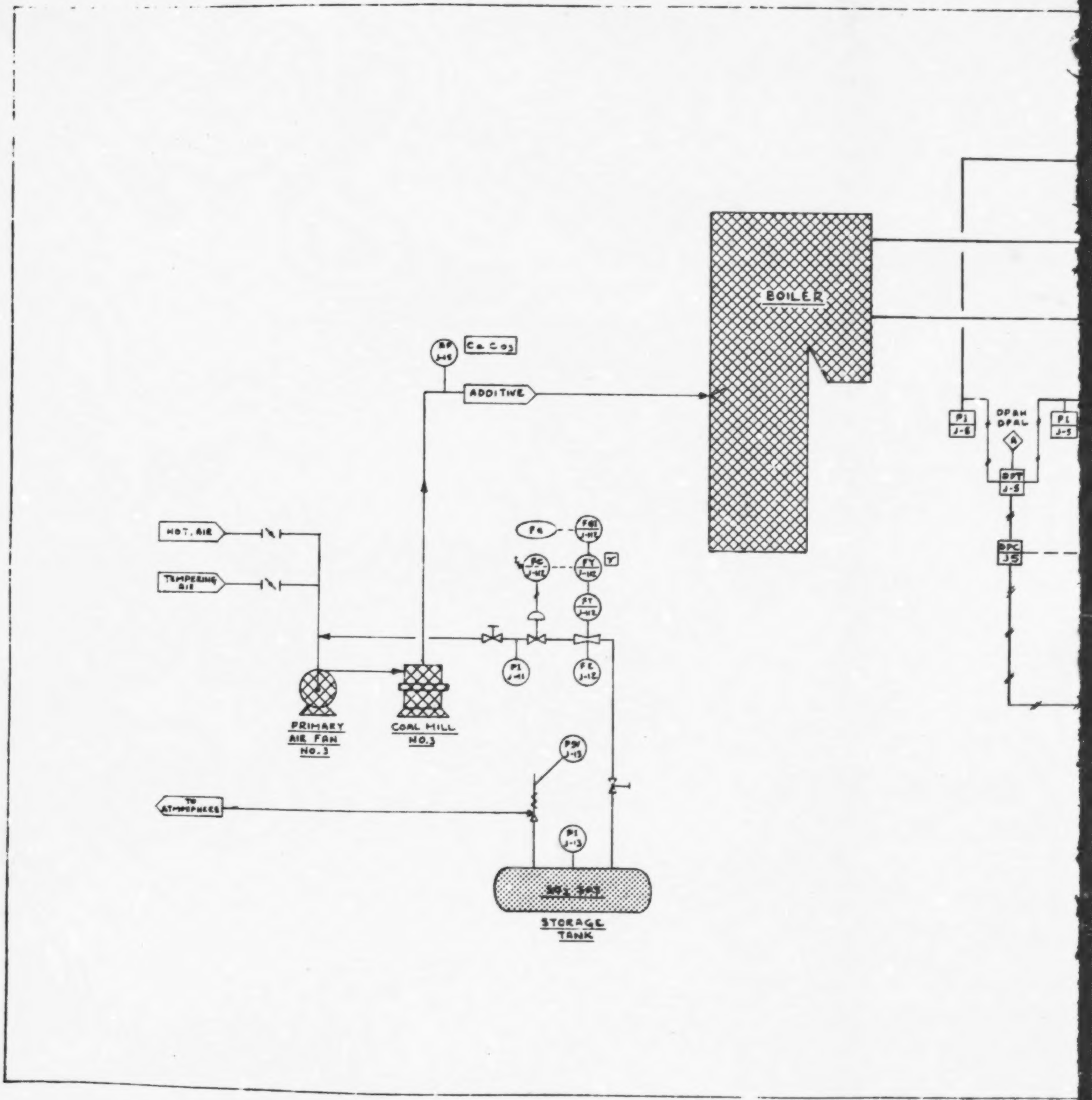
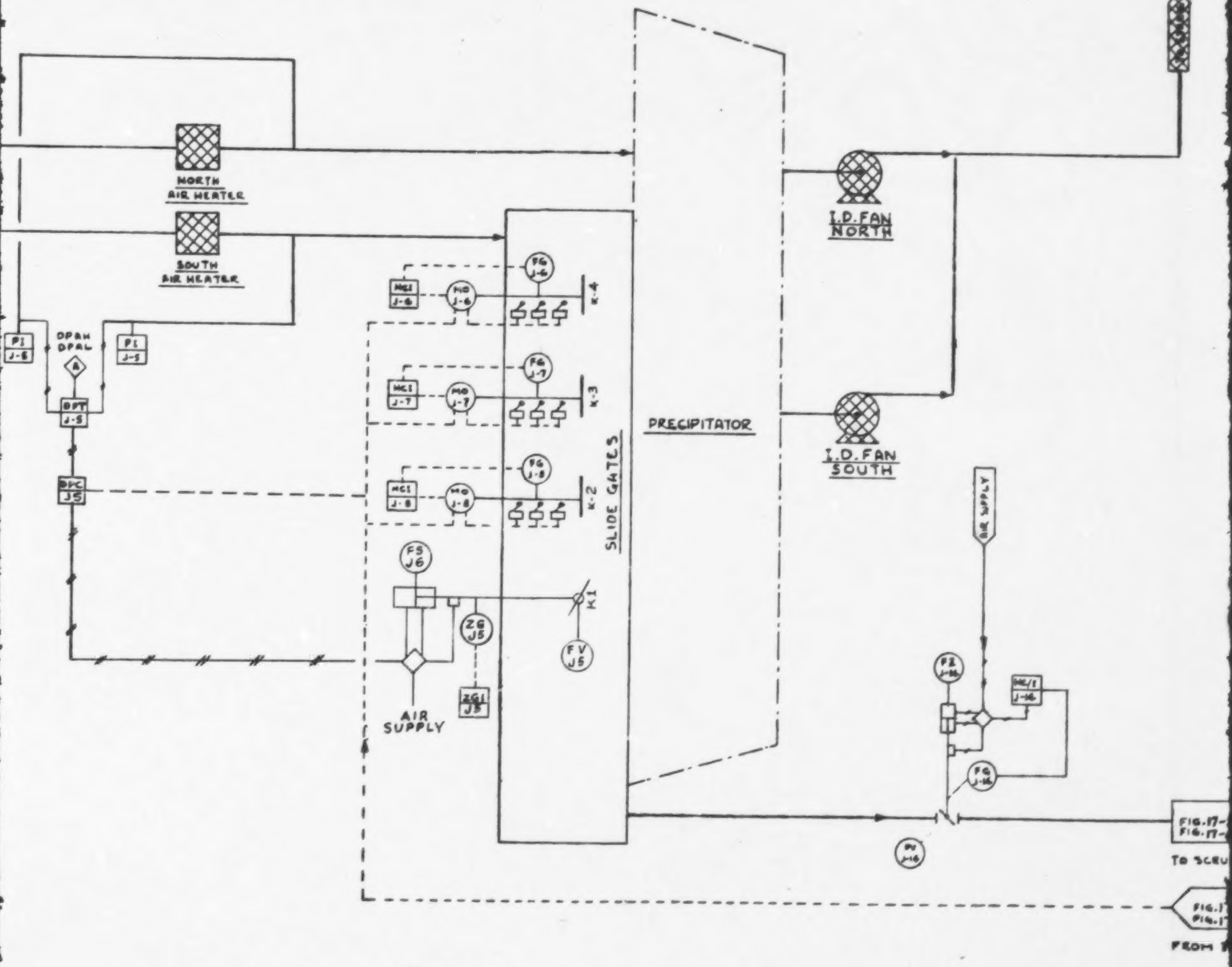
PROCESS PIPING & INSTRUMENTATION DIAGRAM
PLANT NO. 2X

6955	FIGURE 17 - 6	0

D


BOILER
BF J-15
CaCO3
ADDITIVE
HOT. AIR
TEMPERING AIR
FQI J-12
FC J-12
FY J-12
FT J-12
FE J-12
PI J-11
PRIMARY AIR FAN NO. 3
COAL MILL NO. 3
PSV J-13
TO ATMOSPHERE
PI J-13
SO2 SO3
STORAGE TANK
PI J-6
DPAH DPAL
A
PI J-5
DPT J-5
DPC J5

A


NORTH AIR HEATER
SOUTH AIR HEATER
PI J-6
DPAH DPAL
A
PI J-5
DPT J-5
DPC J5
HCI J-6
MO J-6
FG J-6
K-4
HCI J-7
MO J-7
FG J-7
K-3
HCI J-8
MO J-8
FG J-8
K-2
SLIDE GATES
FS J6
ZG J5
ZGI J5
FV J5
K1
AIR SUPPLY
PRECIPITATOR
I.D. FAN NORTH
I.D. FAN SOUTH
AIR SUPPLY
FZ J-16
HC/I J-16
FG J-16
PV J-16
FIG.17-
FIG.17-
TO SCRU
FIG.17
FIG.17
FROM

B

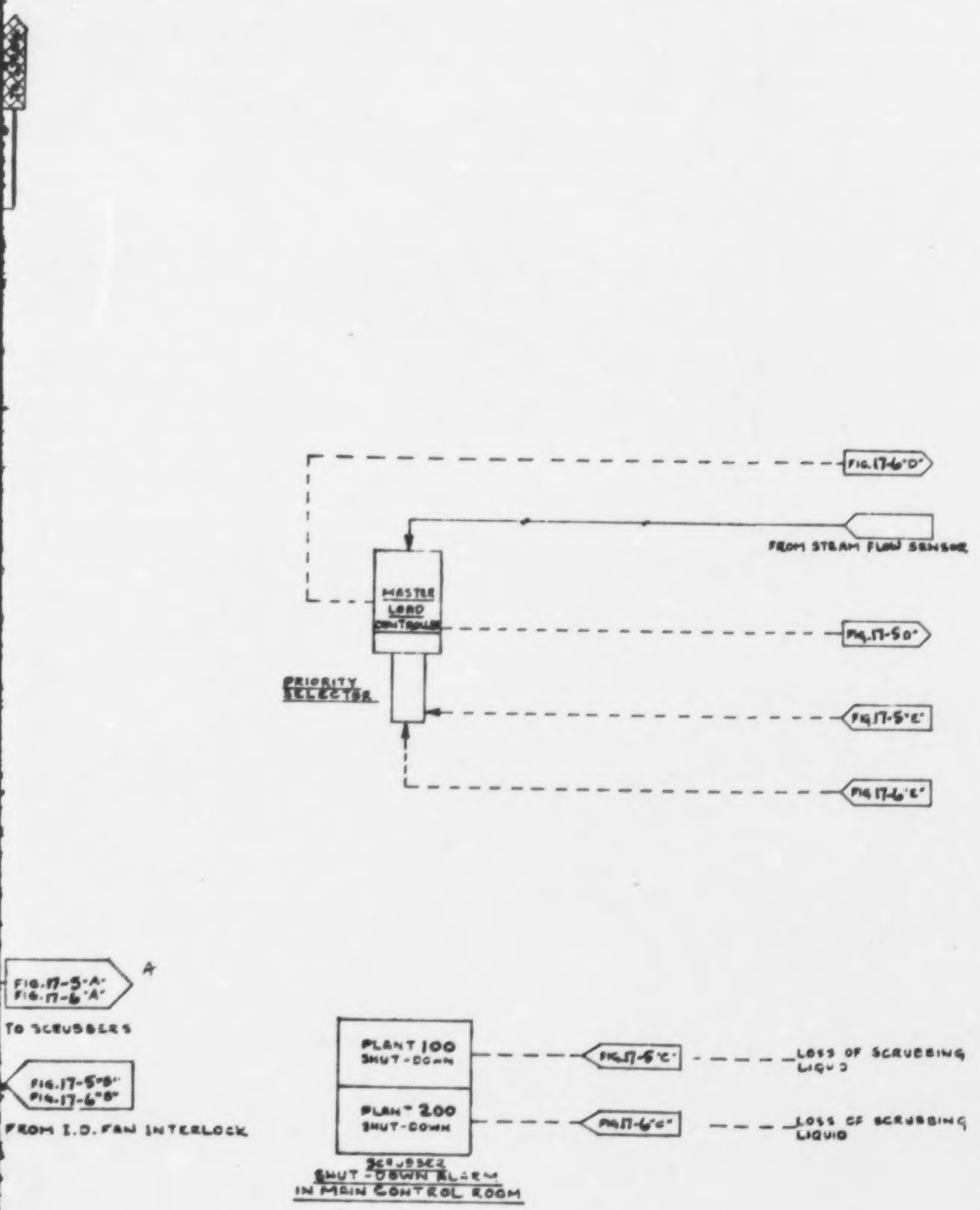


FIG.17-6"D"
FROM STEAM FLOW SENSOR
MASTER LOAD CONTROLLER
FIG.17-5"D"
PRIORITY SELECTOR
FIG.17-5"E"
FIG.17-6"E"
FIG.17-5"A"
FIG.17-6"A"
A
TO SCRUBBERS
FIG.17-5"B"
FIG.17-6"B"
FROM I.D. FAN INTERLOCK
PLANT 100 SHUT-DOWN
PLANT 200 SHUT-DOWN
FIG.17-5"C"
FIG.17-6"C"
LOSS OF SCRUBBING LIQUID
LOSS OF SCRUBBING LIQUID
SCRUBBER SHUT-DOWN ALARM IN MAIN CONTROL ROOM

SYMBOLS & ABBREVIATIONS

○ LOCAL MOUNTED DEVICE

⊟ DEVICE LOCATED IN BOILER CONTROL ROOM

◯ DATA ACQUISTION INPUT

GATE POSITIONING SWITCH

○ DEVICE LOCATED IN TEST FACILITY CONTROL CENTER

▩ AQUEOUS EQUIPMENT

▨ FLUE GAS

▦ FLUE GAS EQUIPMENT

NOTES

FOR GENERAL NOTES, SEE FIGURE 3-8

ALTERNATIVE 2

△
△
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FLUE GAS INSTRUMENTATION & CONTROL DIAGRAM

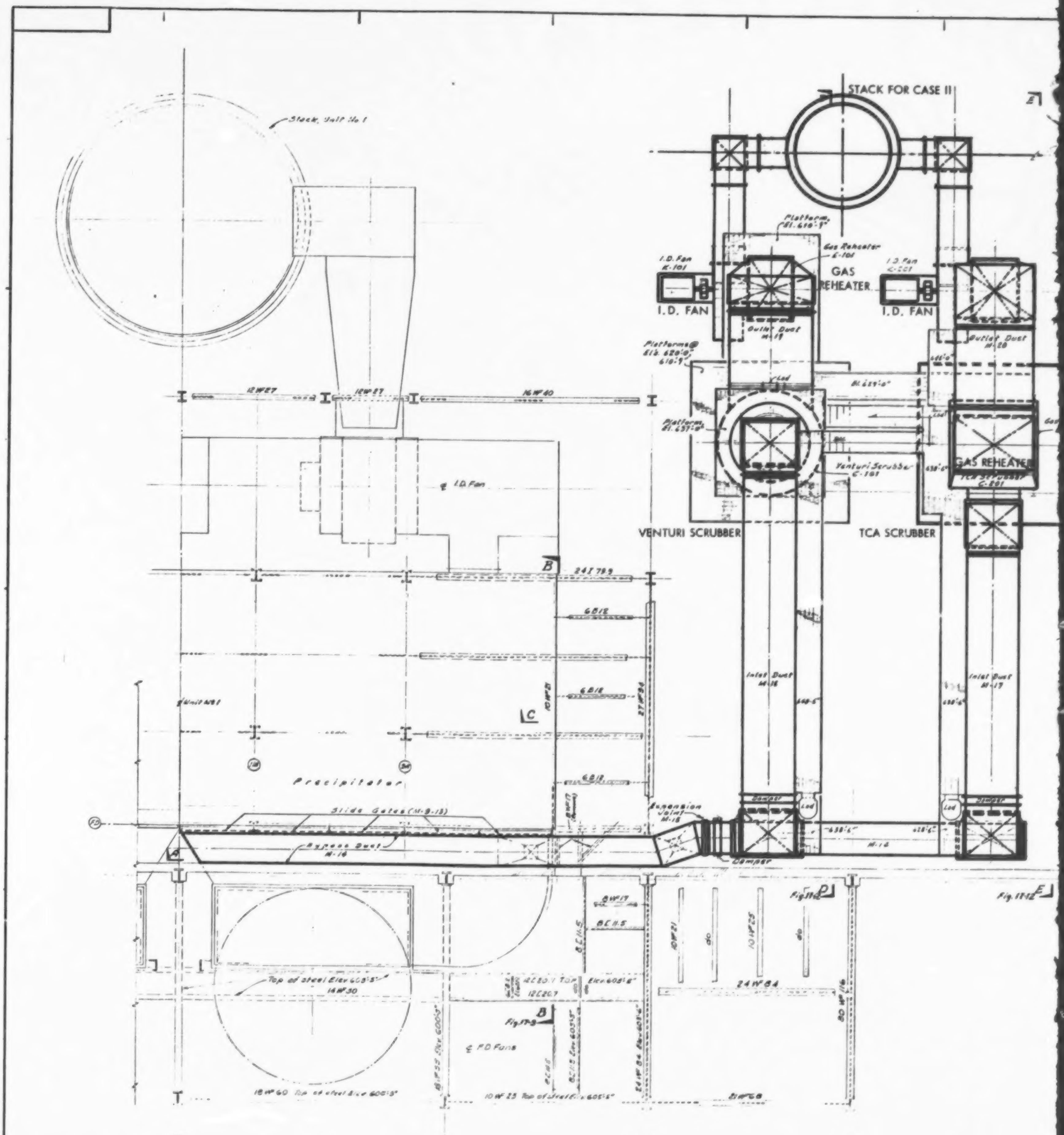
BECHTEL

6953

FIGURE 17 - 7

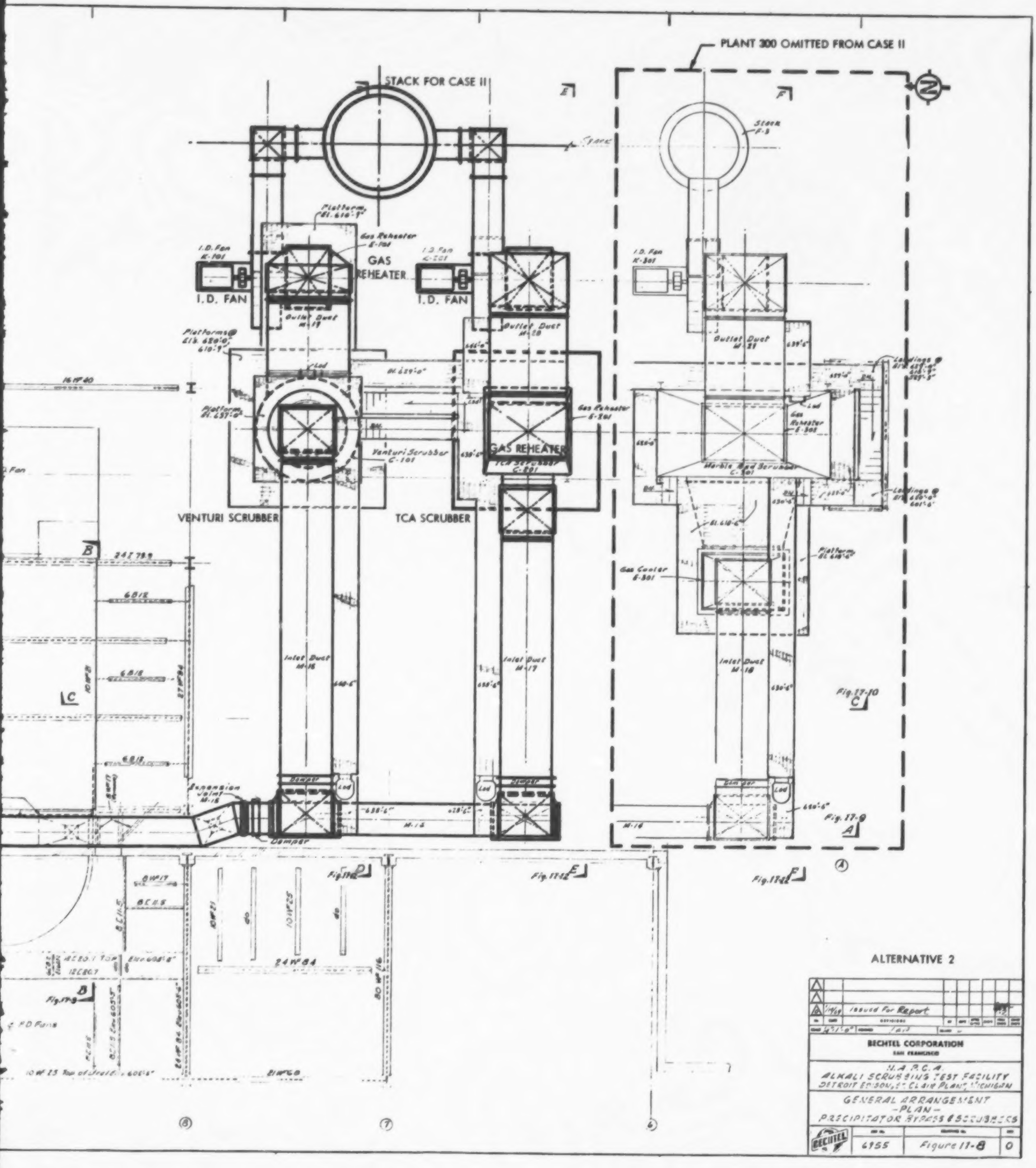
0

C



STACK FOR CASE II
Stack, Unit No. 1
Platform El. 616'-9"
Gas Reheater E-101
GAS REHEATER
I.D. Fan K-101
I.D. FAN
I.D. Fan K-201
I.D. FAN
Outlet Duct M-19
Outlet Duct M-20
Platforms @ Elb. 620'-0", 616'-9"
El. 637'-0"
Platform El. 637'-0"
Venturi Scrubber C-101
GAS REHEATER
TCA Scrubber C-201
VENTURI SCRUBBER
TCA SCRUBBER
12 WF 27
12 WF 27
16 WF 40
℄ I.D. Fan
24 I 79.9
6 B 12
6 B 12
6 B 12
10 WF 21
27 WF 94
℄ Unit No. 1
Precipitator
Inlet Duct M-16
Inlet Duct M-17
Slide Gates (M-9-13)
Bypass Duct M-14
Expansion Joint M-15
Damper
M-16
8 WF 17
8 C 11.5
10 WF 21
10 WF 25
do
do
24 WF 84
30 WF 116
Top of steel Elev 605'-5"
14 WF 30
12 C 20.7 Top Elev 605'-6"
12 C 20.7
℄ F.D. Fans
18 WF 60 Top of steel Elev 600'-5"
10 WF 25 Top of steel Elev 605'-5"
21 WF 68
Fig. 17-9
Fig. 17-10
Fig. 17-12
B
C
D
E
A
11
9
8
7

A


PLANT 300 OMITTED FROM CASE II
STACK FOR CASE II
Stack
Stack F-3
I.D. Fan K-101
I.D. FAN
Platform El. 616'-7"
Gas Reheater E-101
GAS REHEATER
I.D. Fan K-201
I.D. FAN
I.D. Fan K-301
Outlet Duct M-19
Outlet Duct M-20
Outlet Duct M-21
Platforms @ Elb. 620'-0", 610'-7"
Platform El. 637'-0"
El. 629'-0"
Gas Reheater E-201
GAS REHEATER
Venturi Scrubber C-101
TCA Scrubber C-201
VENTURI SCRUBBER
TCA SCRUBBER
Gas Reheater E-301
Marble Bed Scrubber C-301
Landings @
Landings @
El. 618'-6"
Gas Cooler E-301
Platform El. 618'-6"
Inlet Duct M-16
Inlet Duct M-17
Inlet Duct M-18
Damper
Damper
Damper
Expansion Joint M-15
M-16
M-16
Fig. 17-10
Fig. 17-9
Fig. 17-12
Fig. 17-12
Fig. 17-12
Fig. 17-9
ALTERNATIVE 2

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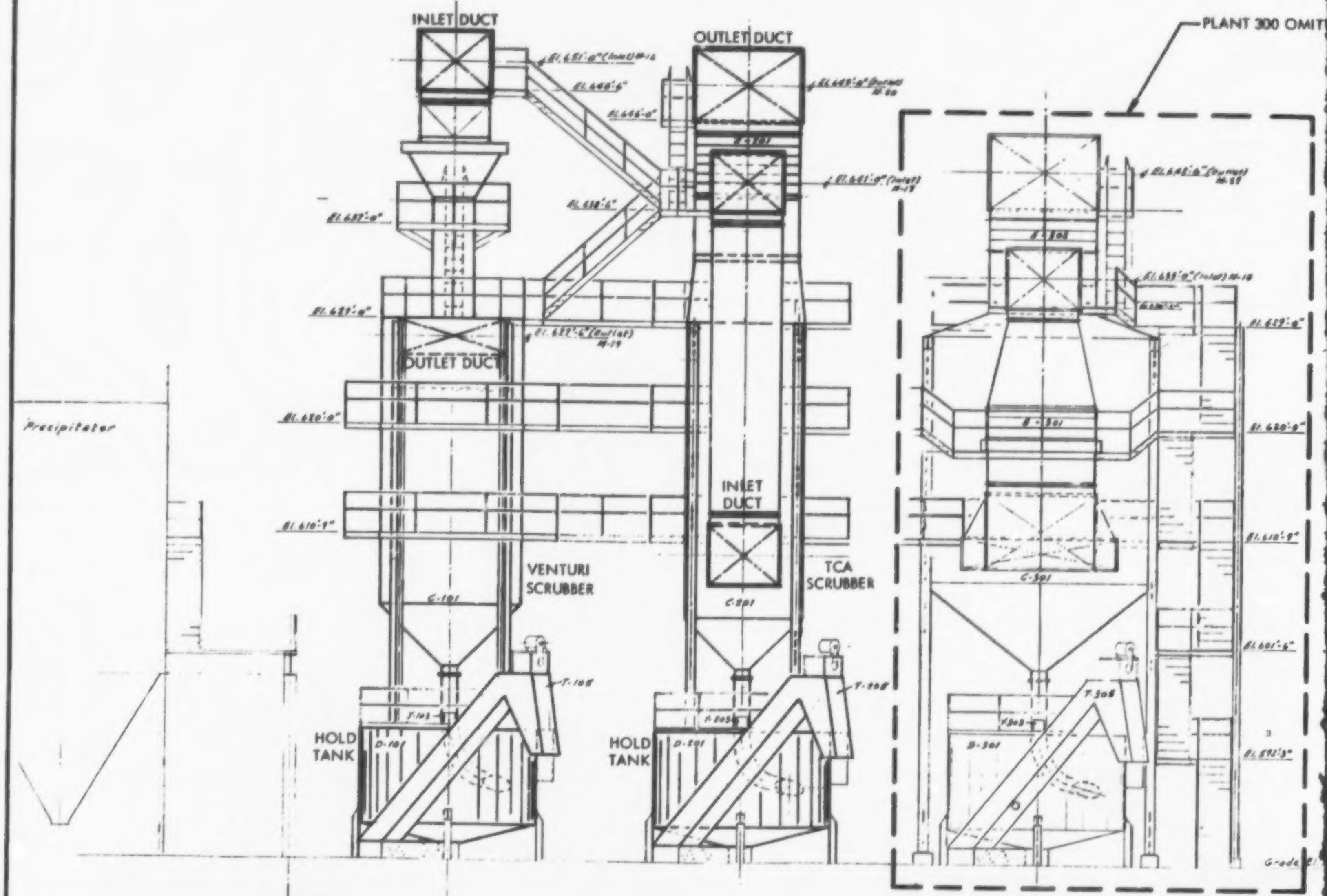
GENERAL ARRANGEMENT
-PLAN-
PRECIPITATOR BYPASS & SCRUBBERS

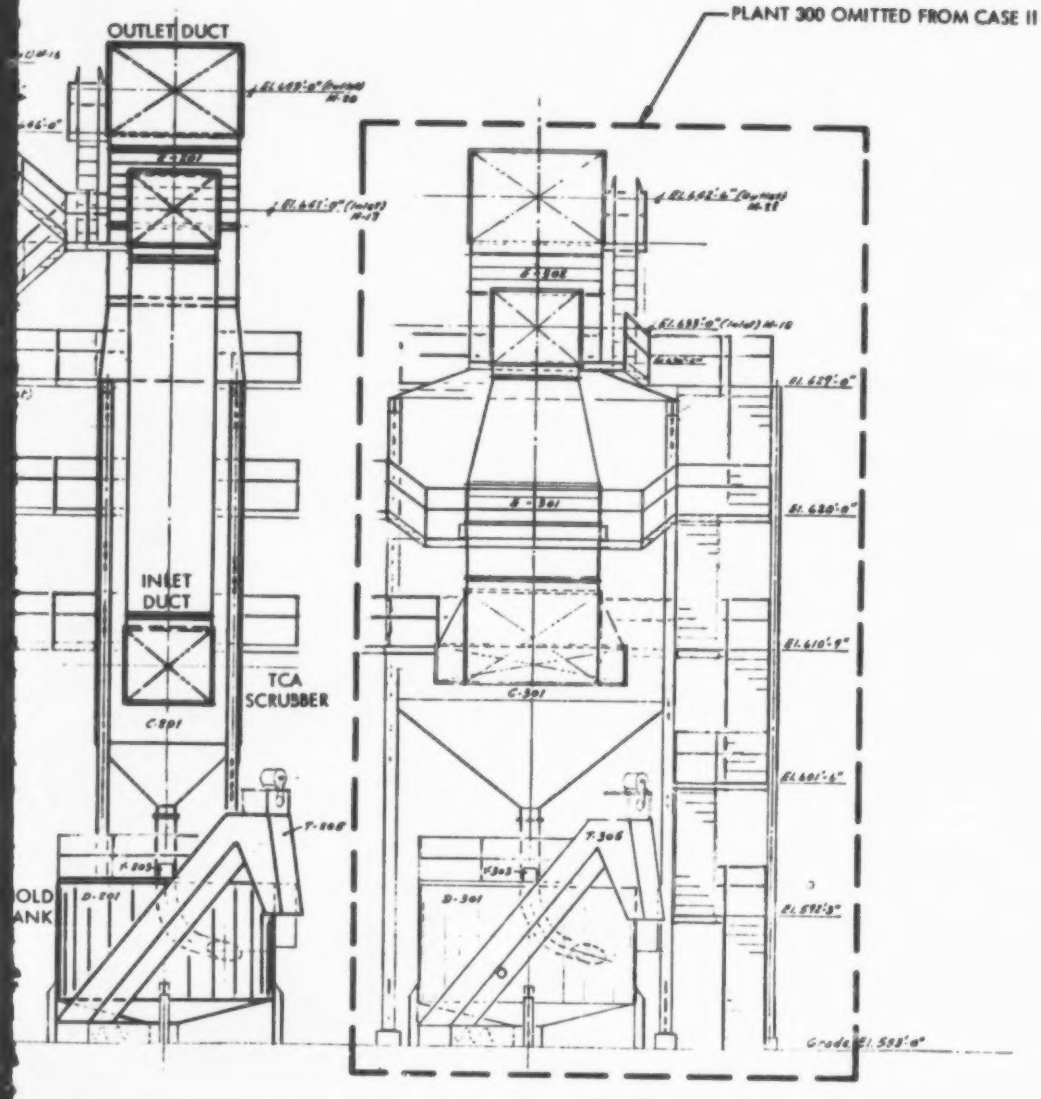
6955	Figure 17-8	0

B


INLET DUCT
OUTLET DUCT
PLANT 300 OMIT
OUTLET DUCT
INLET DUCT
Precipitator
VENTURI SCRUBBER
TCA SCRUBBER
C-101
C-201
C-301
HOLD TANK
HOLD TANK
D-101
D-201
D-301
T-105
T-108
T-208
T-308
El. 629'-0"
El. 620'-0"
El. 610'-9"
El. 601'-6"
B-301
Grade El.

ELEVATION C-C
Looking East

A


OUTLET DUCT
El. 649'-0" (Outlet) M-20
El. 641'-0" (Inlet) M-17
INLET DUCT
TCA SCRUBBER
C-201
T-206
F-203
D-201
OLD
ANK
PLANT 300 OMITTED FROM CASE II
El. 642'-6" (Outlet) M-22
E-302
El. 633'-0" (Inlet) M-18
El. 629'-0"
E-301
El. 620'-0"
El. 610'-9"
C-301
El. 601'-6"
T-306
F-303
D-301
El. 592'-3"
Grade El. 583'-0"
ELEVATION C-C
Looking East

ALTERNATIVE 2

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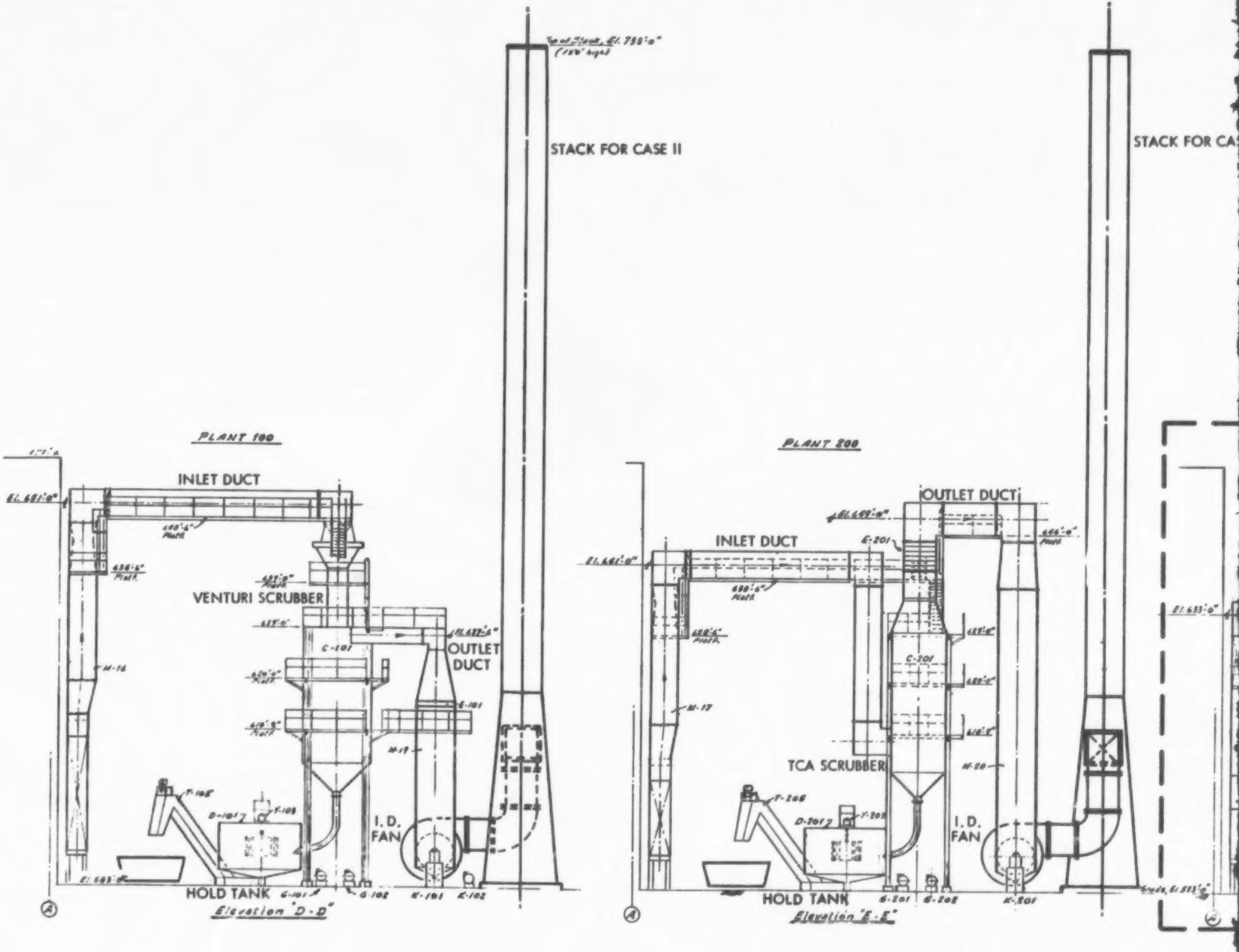
DETROIT EDISON ST. CLAIR PLANT, MICHIGAN

GENERAL ARRANGEMENT
SCRUBBERS
ELEVATION C-C

JOB No.	DRAWING No.	REV
6555	Figure 17-9	0

B

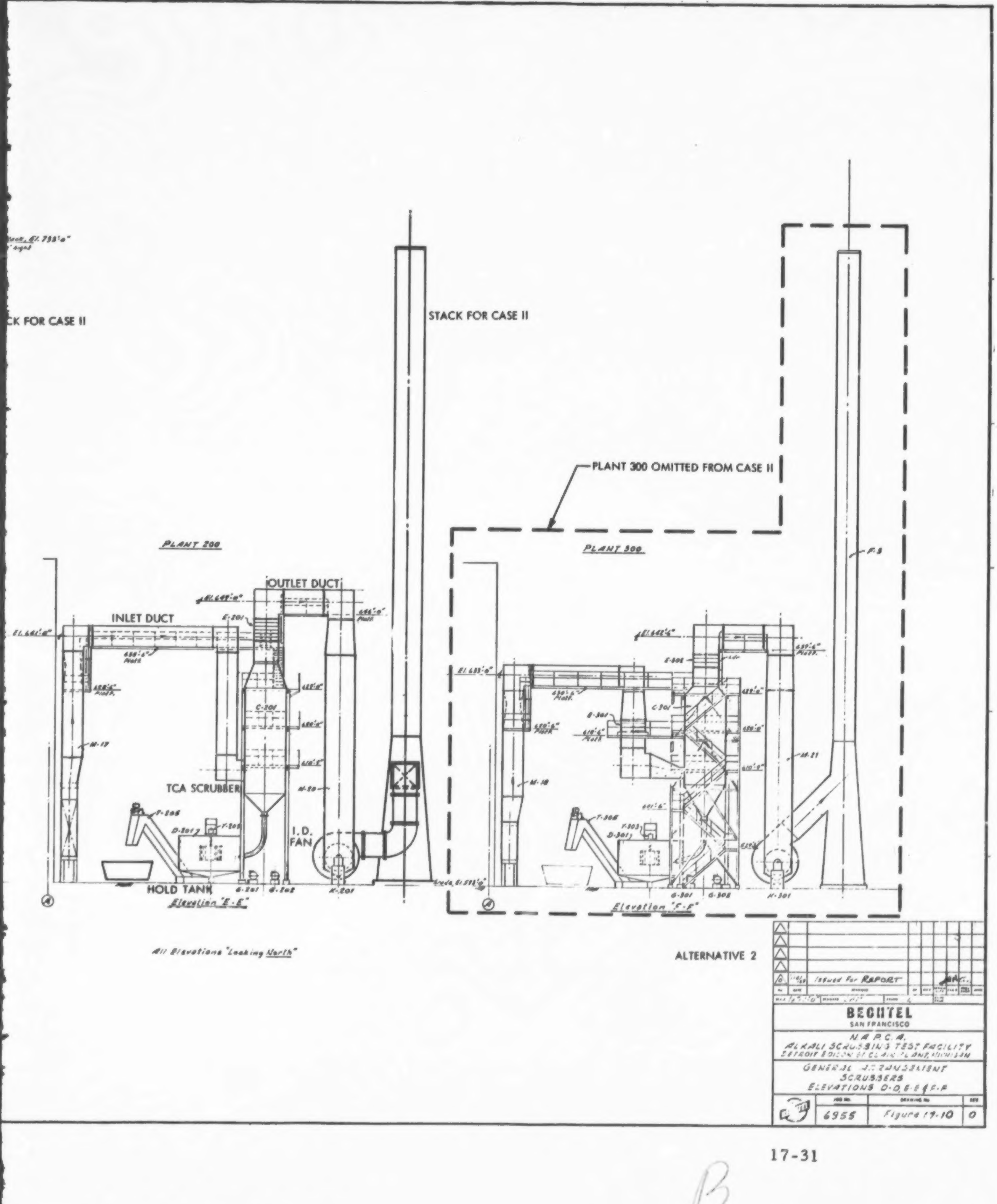

PLANT 100
INLET DUCT
El. 681'-0"
680'-6" Platf.
686'-6" Platf.
VENTURI SCRUBBER
M-16
C-101
OUTLET DUCT
E-101
M-19
T-105
D-101
T-103
I. D. FAN
HOLD TANK
G-101
G-102
K-101
K-102
Top of Stack, El. 793'-0"
(150' high)
STACK FOR CASE II
PLANT 200
OUTLET DUCT
INLET DUCT
El. 681'-0"
E-201
680'-6" Platf.
M-17
C-201
TCA SCRUBBER
M-20
T-206
D-201
T-203
I. D. FAN
HOLD TANK
G-201
G-202
K-201
STACK FOR CA
Grade, El. 583'-0"

Elevation "D-D"

Elevation "E-E"

All Elevations "Looking North"

A


Stack, El. 733'-0"
CK FOR CASE II
STACK FOR CASE II
PLANT 300 OMITTED FROM CASE II
PLANT 200
OUTLET DUCT
El. 649'-0"
E-201
656'-0" Platf.
El. 641'-0"
INLET DUCT
630'-6" Platf.
628'-6" Platf.
625'-0"
C-201
620'-0"
618'-5"
M-17
TCA SCRUBBER
M-20
T-206
D-201
T-205
I.D. FAN
HOLD TANK
G-201
G-202
K-201
Grade, El. 582'-0"
Elevation "E-E"
All Elevations "Looking North"
PLANT 300
F-3
El. 642'-6"
E-302
Ldr.
639'-6" Platf.
El. 633'-0"
630'-6" Platf.
629'-0"
C-301
E-301
620'-6" Platf.
619'-6" Platf.
620'-0"
M-21
610'-0"
M-18
601'-6"
T-306
T-303
D-301
G-301
G-302
K-301
Elevation "F-F"
ALTERNATIVE 2
0
Issued for REPORT
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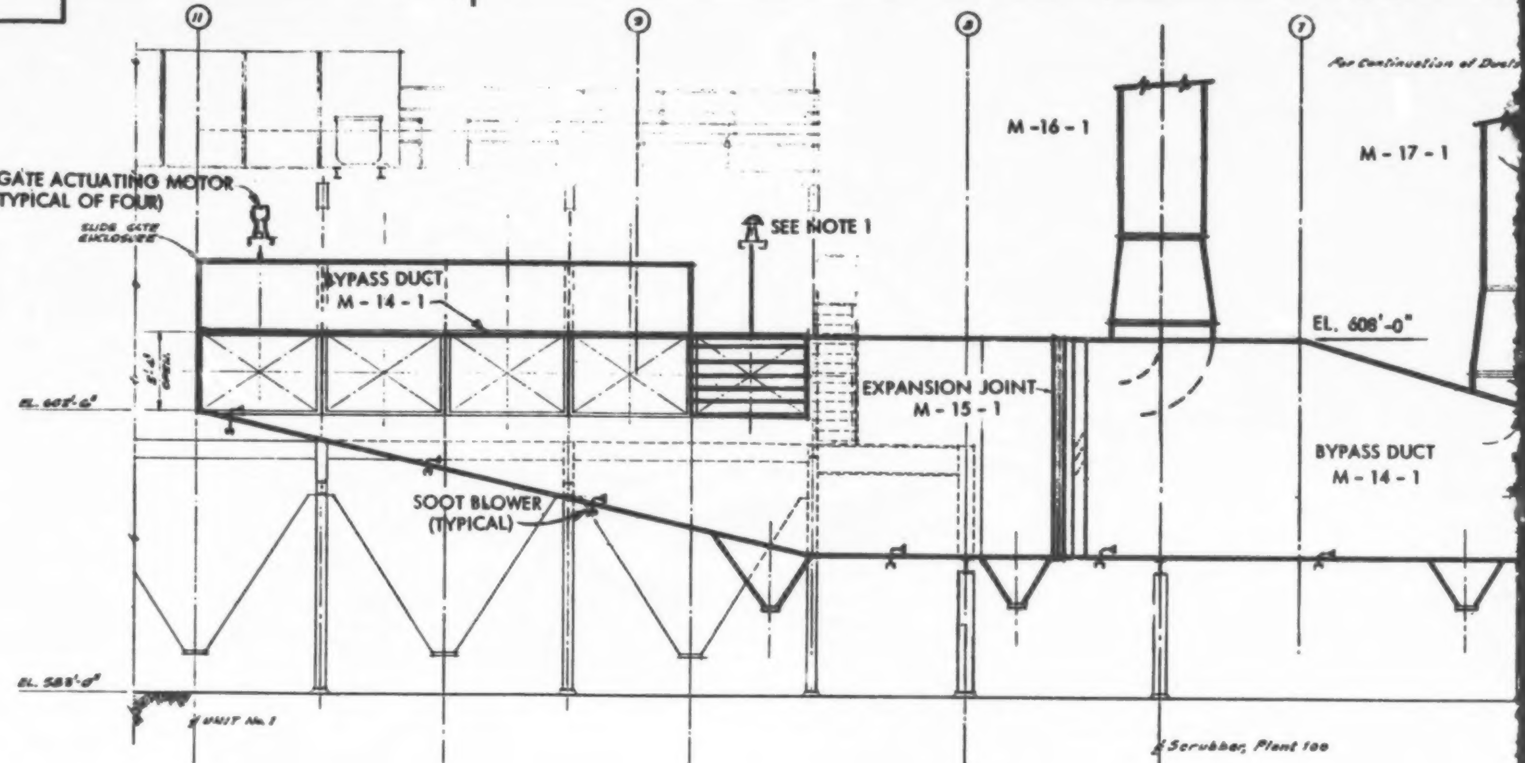
ALKALI SCRUBBING TEST FACILITY
DETROIT EDISON ST. CLAIR PLANT, MICHIGAN
GENERAL ARRANGEMENT
SCRUBBERS
ELEVATIONS D-D, E-E & F-F
JOB No.
DRAWING No.
REV
6955
Figure 17-10
0

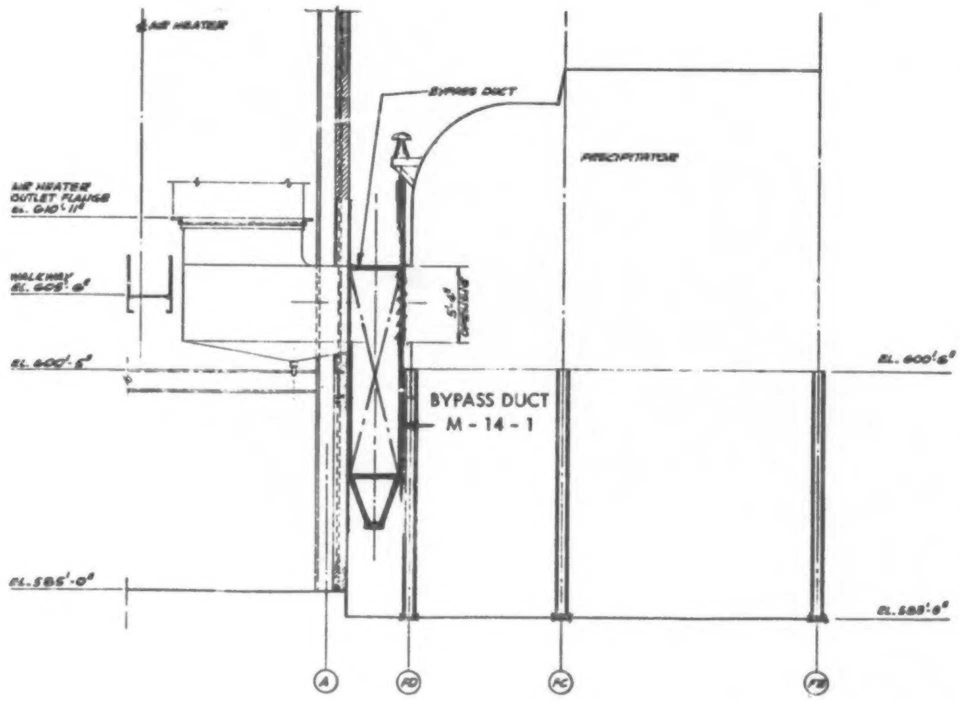
B


11
9
8
7
For Continuation of Ducts
M -16 - 1
M - 17 - 1
SLIDE GATE ACTUATING MOTOR
(TYPICAL OF FOUR)
SLIDE GATE ENCLOSURE
SEE NOTE 1
BYPASS DUCT
M - 14 - 1
5'-4" OPENING
EL. 605'-6"
EXPANSION JOINT
M - 15 - 1
EL. 608'-0"
BYPASS DUCT
M - 14 - 1
SOOT BLOWER
(TYPICAL)
EL. 585'-0"
℄ UNIT No. 1
℄ Scrubber, Plant 100

SECTION A-A
LOOKING EAST

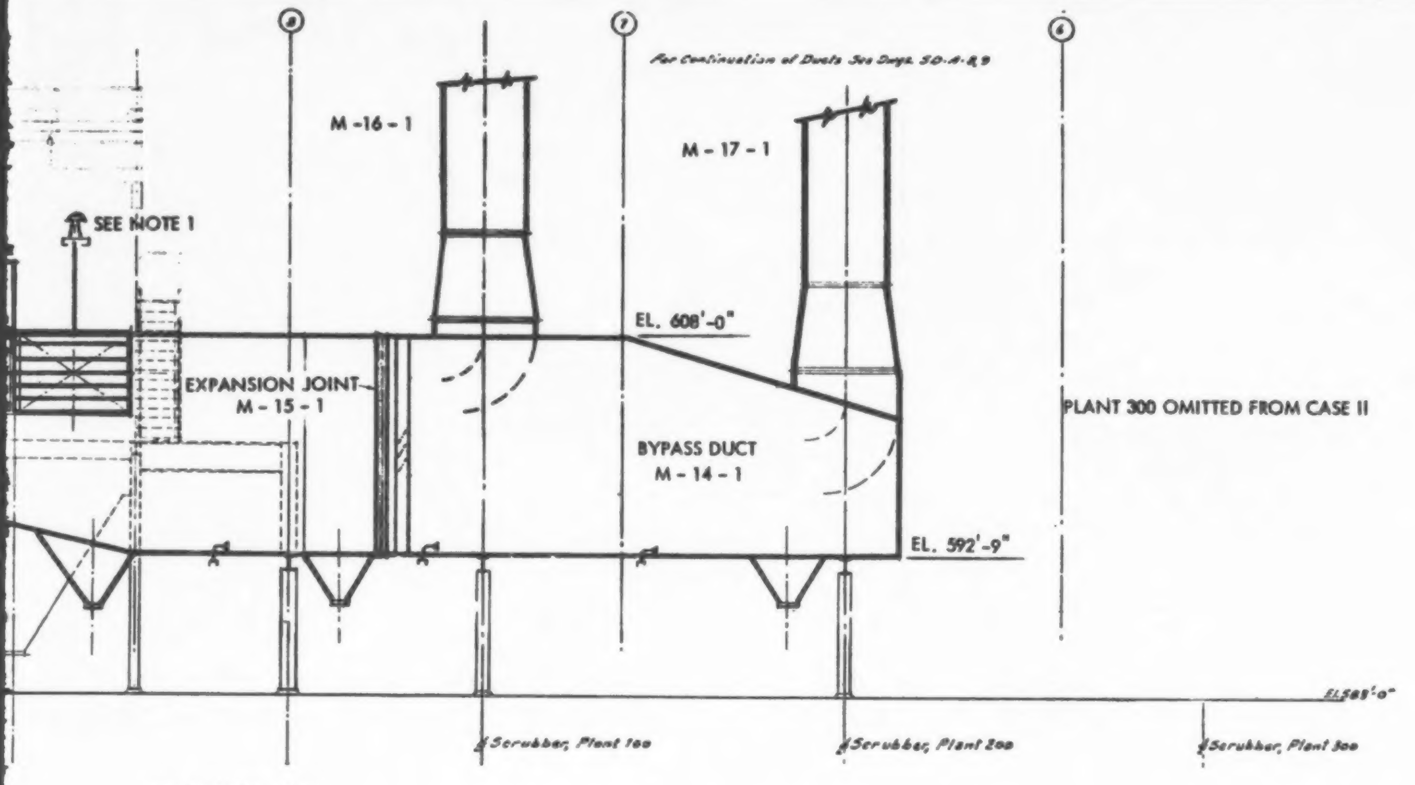
NOTE 1:

CHA
WITH
CON
SLIDE
MOT

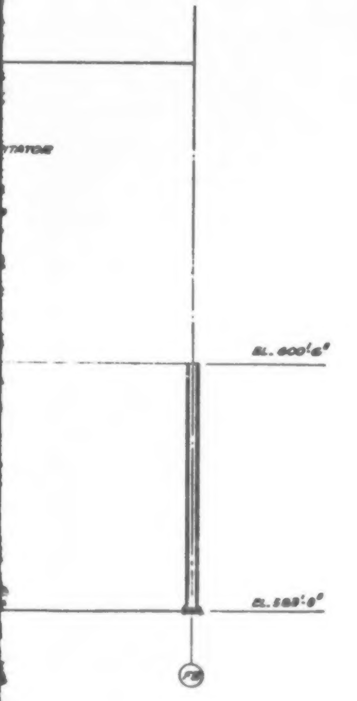

℄ AIR HEATER
BYPASS DUCT
PRECIPITATOR
AIR HEATER OUTLET FLANGE EL. 610'-11"
WALKWAY EL. 605'-6"
5'-4" OPENING
EL. 600'-5"
EL. 600'-5"
BYPASS DUCT
M - 14 - 1
EL. 585'-0"
EL. 585'-0"
A
FD
FC
FB

SECTION B-B
LOOKING NORTH

A


For Continuation of Ducts See Dwgs. SD-A-8,9
8
7
6
M-16-1
M-17-1
SEE NOTE 1
EL. 608'-0"
EXPANSION JOINT
M-15-1
BYPASS DUCT
M-14-1
PLANT 300 OMITTED FROM CASE II
EL. 592'-9"
EL 583'-0"
℄ Scrubber, Plant 100
℄ Scrubber, Plant 200
℄ Scrubber, Plant 300

SECTION A-A
LOOKING EAST


TATOR
EL. 600'-6"
EL. 583'-0"
F8

NOTE 1:

CHANGE THIS SLIDE GATE TO FLAPPER TYPE WITH AIR PISTON OPERATOR AND AUTOMATIC CONTROL "HALF BOILER"ΔP SENSOR. FOUR SLIDE GATES REMAIN THE SAME WITH MANUAL MOTORIZED OPERATION.

ALTERNATIVE 2

△								
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V.A.P.C.A.
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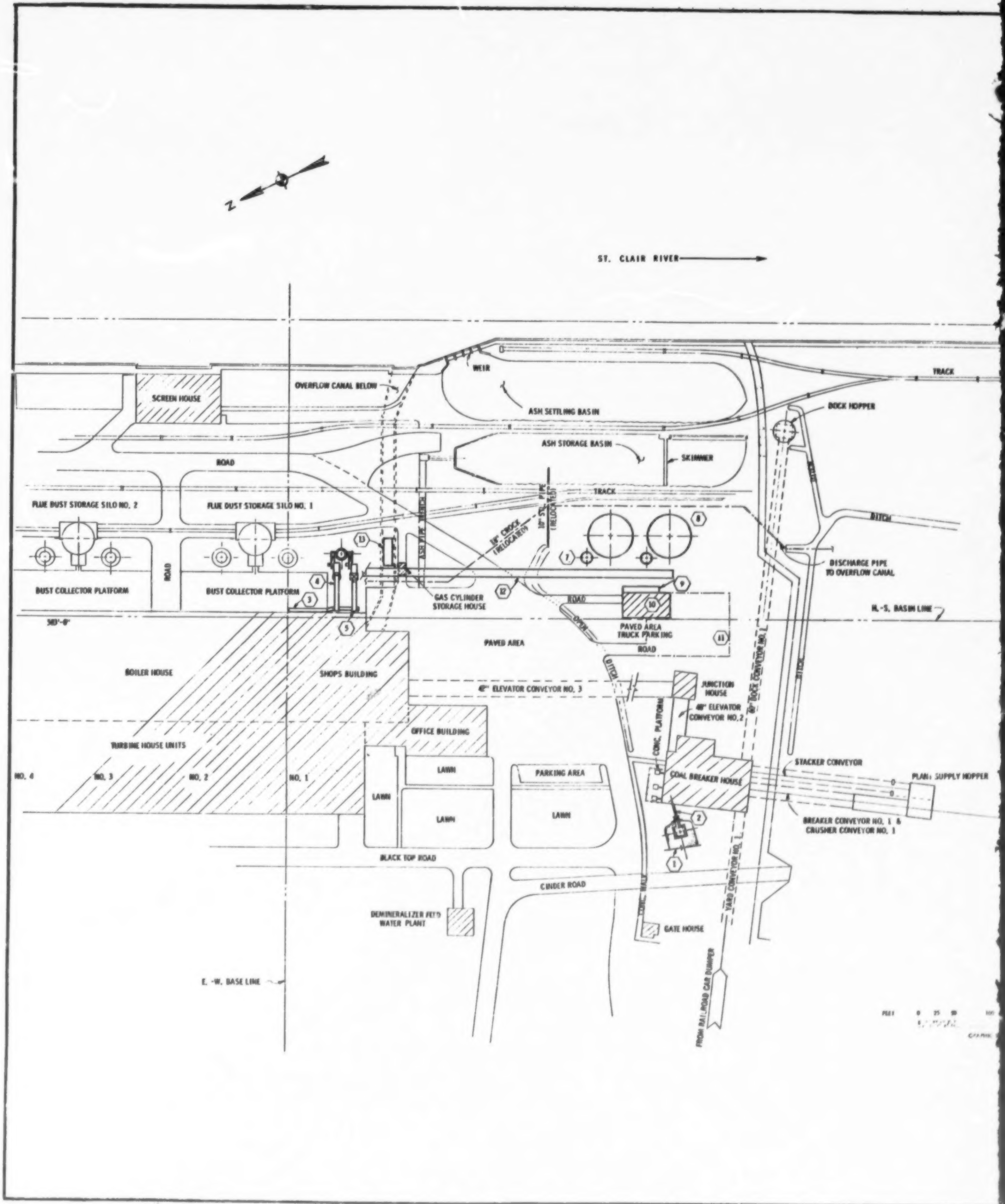
DETROIT EDISON, ST. CLAIR PLANT, MICHIGAN

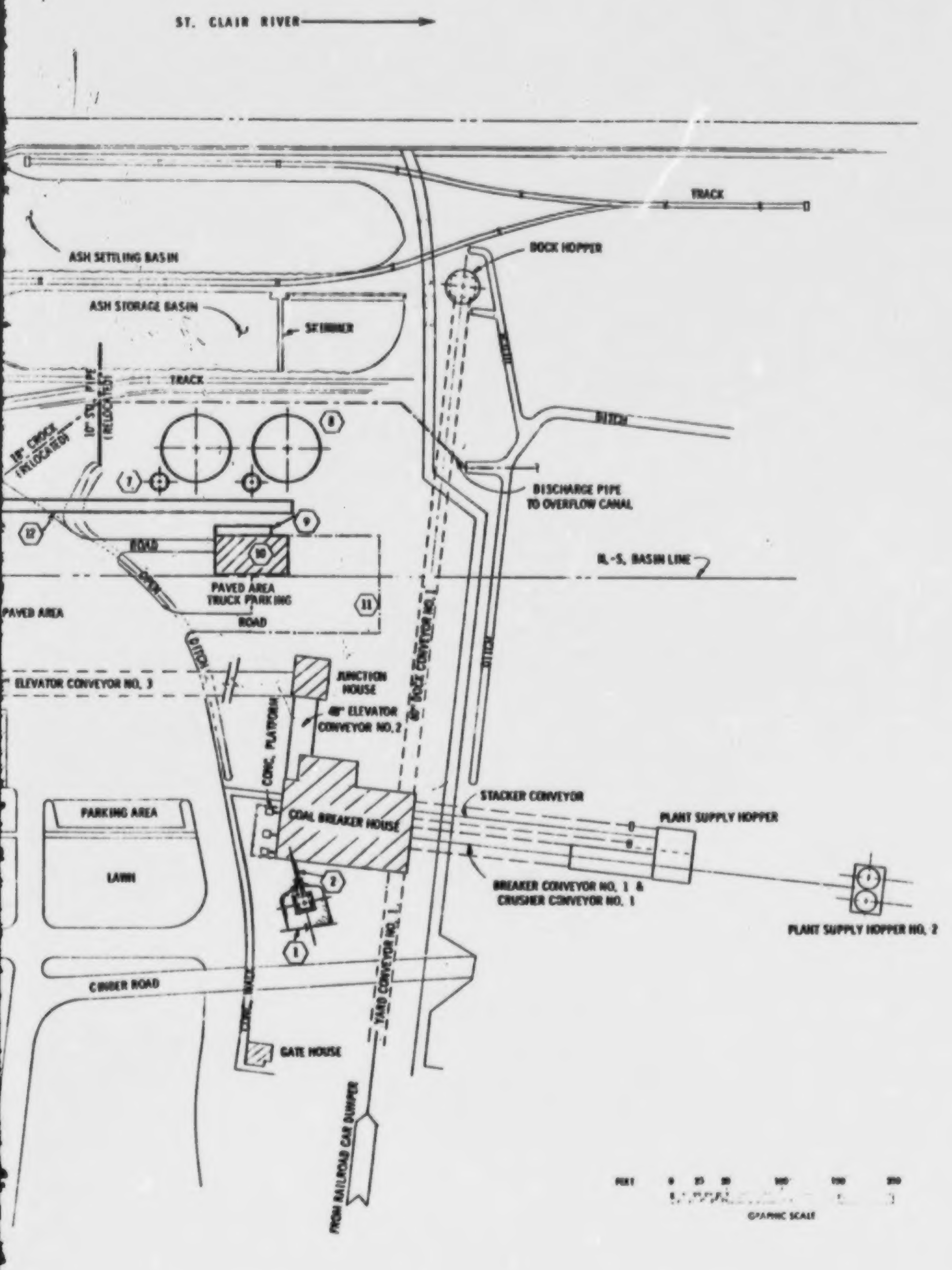
PRECIPITATOR BYPASS DUCT
SECTIONS A-A & B-B

6355 | Figure 17-11 | 0

B


N
ST. CLAIR RIVER
WEIR
OVERFLOW CANAL BELOW
SCREEN HOUSE
ASH SETTLING BASIN
TRACK
DOCK HOPPER
ASH STORAGE BASIN
SKIMMER
ROAD
TRACK
FLUE DUST STORAGE SILO NO. 2
FLUE DUST STORAGE SILO NO. 1
ASH PIPE TRENCH
18" CHOCK (RELOCATED)
10" ST. PIPE (RELOCATED)
DITCH
DISCHARGE PIPE TO OVERFLOW CANAL
ROAD
DUST COLLECTOR PLATFORM
DUST COLLECTOR PLATFORM
GAS CYLINDER STORAGE HOUSE
ROAD
OPEN
PAVED AREA TRUCK PARKING
ROAD
N.-S. BASIN LINE
583'-0"
PAVED AREA
BOILER HOUSE
SHOPS BUILDING
DITCH
42" ELEVATOR CONVEYOR NO. 3
JUNCTION HOUSE
48" ELEVATOR CONVEYOR NO. 2
CONC. PLATFORM
60" DOCK CONVEYOR NO. 1
DITCH
OFFICE BUILDING
TURBINE HOUSE UNITS
NO. 4
NO. 3
NO. 2
NO. 1
LAWN
LAWN
LAWN
PARKING AREA
LAWN
COAL BREAKER HOUSE
STACKER CONVEYOR
PLANT SUPPLY HOPPER
BREAKER CONVEYOR NO. 1 & CRUSHER CONVEYOR NO. 1
BLACK TOP ROAD
CINDER ROAD
CONC. WALK
YARD CONVEYOR NO. 1
DEMINERALIZER FEED WATER PLANT
GATE HOUSE
E.-W. BASE LINE
FROM RAILROAD CAR DUMPER
FEET 0 25 50 100
1
2
3
4
5
7
8
9
10
11
12
13

A


ST. CLAIR RIVER
TRACK
ASH SETTLING BASIN
DOCK HOPPER
ASH STORAGE BASIN
SKIMMER
TRACK
10" STL. PIPE (RELOCATED)
18" CROCK (RELOCATED)
DITCH
8
7
DISCHARGE PIPE TO OVERFLOW CANAL
9
12
ROAD
10
B.-S. BASIN LINE
PAVED AREA TRUCK PARKING
OPEN
11
PAVED AREA
ROAD
DITCH
DITCH
ELEVATOR CONVEYOR NO. 3
JUNCTION HOUSE
48" ELEVATOR CONVEYOR NO. 2
CONC. PLATFORM
TOLE CONVEYOR NO. 1
STACKER CONVEYOR
PARKING AREA
COAL BREAKER HOUSE
PLANT SUPPLY HOPPER
LAWN
2
1
BREAKER CONVEYOR NO. 1 & CRUSHER CONVEYOR NO. 1
PLANT SUPPLY HOPPER NO. 2
CINDER ROAD
CONC. WALK
YARD CONVEYOR NO. 1
GATE HOUSE
FROM RAILROAD CAR DUMPER
FEET 0 25 50 100 150 200
GRAPHIC SCALE

LEGEND

1 ____ ADDITIVE STORAGE AREA
2 ____ FEED HOPPER REDLER CONVEYOR/ELEVATOR
3 ____ MAIN BY-PASS DUCT
4 ____ SCRUBBER SYSTEM 100
5 ____ SCRUBBER SYSTEM 200

7 ____ PROCESS WATER HOLD TANKS
8 ____ CLARIFIERS
9 ____ SETTLING TANK
10 ____ FILTER BUILDING
11 ____ SOLIDS STORAGE AREA
12 ____ OVERHEAD PIPE RACK
13 ____ LAB. & INSTRUMENT TRAILER

ALTERNATIVE 2

△								
△								
△								
△								
6	5/75	Issued for Report						

BECHTEL
SAN FRANCISCO

[illegible]
ALKALI SCRUBBING TEST FACILITY
[illegible] ST. CLAIR [illegible]

PLOT PLAN

JOB NO.	DRAWING NO.	REV
1955	FIGURE 17-12	0

B

Table 17-7

ALTERNATIVE 2 MODIFICATIONS TO PHASE I EQUIPMENT LIST*

Item	Description	Former Equip. Nos.
Slide Gate Assy	3 - Guillofine-type, 5' 9" x 8' 4" - 1/4" pl. c. s. w/stiff guides and rubber seals 1 - Full closing Damper	M-9 to M-13
Gate Actuating Motors	2 - 2hp motors (Limitorque) 1 - air motor with auto. controller	K-1 to K-5
Main By-Pass Duct	1 - 3' 9" x 15' 3" high sloping to 9' high in 71' of length 3/16" galv. and insul. w/2" asbestos and weather-proofed w/stiffeners and supports	M-14
Expansion Joint	1 - 3' 9" x 15' 3" double bellows c. s.	M-15
Stacks	1 - 5" dia. at exit; 10' dia. at base x 150' high c. s. gunited	F-1 to F-3
Steam-Coil Flue Gas Reheater	1 - multiple gas burner direct heater, natural gas at 30 psig. 150°F ΔT 23,400,000 Btu/hr	E-201
Induced Draft Fan w/Driver	1 - 188,000 c/m @ 275° F, 35" w. g. static pressure, 1600 hp, 1200 rpm	K-201
Test Settling Tank	eliminated	D-204
Condensate Return Pump w/Driver	eliminated	G-207

* Equipment listed in this table only when modified or eliminated

Table 17-7 (Cont.)

ALTERNATIVE 2 MODIFICATIONS
TO PHASE I EQUIPMENT LIST*

Item	Description	Former Equip. Nos.
Settling Tank Recirc. Pump w/Driver	eliminated	G-208
Collecting and Stacking Conveyor w/Driver	1 - 9" wide conveyor belt w/3" corrugated sides, "L" type, 17° incline x 133' long, 3 hp driver	T-206
PLANT 300	ELIMINATED ENTIRELY	
Unit Heaters	4 - American Air Filters, Model HVE-3 one-row coil Model DT (8 fins/inch) Minimum 850 cfm.	–
Gravity Roof Ventilators	4 - Moffitt Industrial Round Cavity Ventilators, Model 2096, 48" diameter	–
Louvers	10 - Airolite #663 louvers, 4' wide x 5' high, operating type, steel adjustable blades, w/insect screens	–
Power Load Center	1- power load center incl: 1 - 750 KVA, 2.4 KV/480 - 277 V 3 phase, dry-type transformer 2 - units of 2.4 KV. metal-clad switchgear, incl. ammeter, current transformers, voltage and overcurrent relays, and power circuit breaker (stored energy)	P-1

*Equipment listed in this table only when modified or eliminated

Table 17-7 (Cont.)

ALTERNATIVE 2 MODIFICATIONS
TO PHASE I EQUIPMENT LIST*

Item	Description	Former Equip. Nos.
Power Load Center (Cont.)	1 - incoming and metering unit, including kilowatt/hour meter, voltmeter, ammeter, ammeter switch, and current and potential transformers	P-1 (Cont.)
Local Distribution Panels	1 - Distribution Panel, NEMA-12, incl. molded case circuit breakers type TJK and THEF, 8-100A-3P	P-14 P-15
Local Distribution Panel	eliminated	P-16
A. C. Magnetic Full Voltage Motor Starters	600 volt, three overload relays, start-stop push buttons in cover NEMA - 4 enclosure, FVNR 12 - size 3 16 - size 1 NEMA - 12 enclosure FVNR 1 - size 3 6 - size 1 NEMA - 4 enclosure, FVR 3 - size 1	P-21

* Equipment listed in this table only when modified or eliminated

Table 17-8

COMPARISON OF PHASE I AND ALTERNATIVE DESIGN CAPITAL COSTS SUMMARY ($1000)

	Item	Cost				
		Phase I	Alt. 1	Alt. 2	Alt. 3	Alt. 4
Field Costs	Earthwork and Piling	94	75	69	55	45
	Concrete	101	88	85	74	64
	Structural Steel and Misc. Metal	51	47	41	40	30
	Filter Building	26	20	20	17	17
	Ductwork	238	188	178	167	119
	Additive Handling Equipment	144	145	145	145	145
	Flue Gas Equipment	702	485	353	415	200
	Sludge Handling Equipment	531	349	327	212	168
	Maintenance Equipment	44	44	44	44	44
	Piping	525	402	382	323	268
	Electrical	484	443	427	373	254
	Instrumentation	603	521	492	364	343
	Start-up	52	54	50	45	43
	Total Field Cost	3595	2861	2613	2274	1740
Other Costs	Engineering	663	646	612	544	459
	Home Office	187	181	172	152	129
	Contingency	445	368	336	297	232
	Fee	255	209	192	170	133
	Escalation	205	155	145	123	97
	Total Other Costs	1755	1559	1457	1286	1050
	Total Constructed Cost	5350	4420	4070	3560	2790
	Savings over Phase I Design	----	930	1280	1790	2560
	Adjustment of Alt. 2 by adding centrifuge, Gas Reheater, and Induced-Draft Fan			80		
	Revised Total Constructed Cost			4150		
	Revised Savings over Phase I Design			1200		

Table 17-8 (Cont.)

COMPARISON OF PHASE I AND ALTERNATIVE DESIGN CAPITAL COSTS BREAKDOWN ($1000)

Item		Cost				
		Phase I	Alt. 1	Alt. 2	Alt. 3	Alt. 4
Earthwork and Piling	Excavation	11.2	8.2	8.2	5.4	4.8
	Backfill	17.8	12.8	12.8	7.4	7.1
	Dewatering	11.0	10.0	10.0	7.0	6.3
	Bearing Piling	24.0	24.0	18.0	24.0	15.6
	Sheet Piling	21.6	14.4	14.4	8.4	8.4
	CMP Clarifier Tunnels	8.4	5.6	5.6	2.8	2.8
	Sub-Total – Earthwork and Piling	94.0	75.0	69.0	55.0	45.0
Concrete	Scrubber Area Slab	19.8	20.4	17.4	20.4	10.4
	Pipe Support Footings	5.9	5.5	5.5	4.7	4.7
	Pump Foundations	4.5	4.1	4.1	2.5	2.5
	Clarifier Foundations	24.4	17.8	17.8	10.5	10.5
	Limestone Feeding Vault	20.4	21.2	21.2	21.2	21.2
	Filter Building Slab	26.0	19.0	19.0	14.7	14.7
	Sub-Total – Concrete	101.0	88.0	85.0	74.0	64.0
Structural Steel and Misc. Metal	Limestone Feeding Vault	3.8	3.8	3.8	3.8	3.8
	Pipeway	3.3	2.8	2.8	2.5	2.5
	Scrubber Area Platforms	43.0	39.8	33.8	33.2	23.6
	Clarifier Tunnels	0.9	0.6	0.6	0.3	0.3
	Sub-Total – Structural Steel and Misc. Metal	51.0	47.0	41.0	40.0	30.0
Filter Building	Superstructure	17.8	13.2	13.2	11.2	11.2
	Doors	1.8	1.8	1.8	1.8	1.8
	Heating Equipment	6.4	5.0	5.0	4.0	4.0
	Sub-Total – Filter Building	26.0	20.0	20.0	17.0	17.0

Table 17-8 (Cont.)

COMPARISON OF PHASE I AND ALTERNATIVE DESIGN CAPITAL COSTS BREAKDOWN ($1000)

Item		Cost				
		Phase I	Alt. 1	Alt. 2	Alt. 3	Alt. 4
Ductwork	Bypass Ducts	153.0	118.0	113.0	107.0	76.0
	Expansion Joints	5.0	5.0	4.0	5.0	2.0
	Dampers	8.0	8.0	6.0	8.0	4.0
	Insulation	52.0	40.0	38.0	36.0	26.0
	Slide Gate Assemblies and Motors	18.0	15.0	15.0	9.0	9.0
	Remove Section of Existing Duct	2.0	2.0	2.0	2.0	2.0
	Sub-Total — Ductwork	238.0	188.0	178.0	167.0	119.0
Additive Handling Equipment	Feed Hopper with Grating	5.0	5.0	5.0	5.0	5.0
	Redler Conveyor	36.2	36.2	36.2	36.2	36.2
	Conveyor Discharge Chute	4.8	4.8	4.8	4.8	4.8
	Sump Pump with Piping	1.5	1.5	1.5	1.5	1.5
	Bunker Partitions	43.2	44.2	44.2	44.2	44.2
	Remove Section of Existing Pipe	2.0	2.0	2.0	2.0	2.0
	Valves	2.0	2.0	2.0	2.0	2.0
	Gravimetric Feeder	19.3	19.3	19.3	19.3	19.3
	22-inch Pipe	5.0	5.0	5.0	5.0	5.0
	Front End Loader - 3 CY	25.0	25.0	25.0	25.0	25.0
	Sub-Total — Additive Handling Equipment	144.0	145.0	145.0	145.0	145.0
Flue Gas Equipment	Scrubbers	433.0	324.3	216.6	324.3	109.3
	Reheaters	58.0	40.7	32.6	20.0	20.0
	Induced Draft Fans with Motors	94.0	63.0	46.8	31.7	31.7
	Stacks	117.0	57.0	57.0	39.0	39.0
	Sub-Total — Flue Gas Equipment	702.0	485.0	353.0	415.0	200.0

Table 17-8 (Cont.)

COMPARISON OF PHASE I AND ALTERNATIVE DESIGN CAPITAL COSTS BREAKDOWN ($1000)

Item		Cost				
		Phase I	Alt. 1	Alt. 2	Alt. 3	Alt. 4
Maintenance Equipment	Maintenance Trailer	10.0	10.0	10.0	10.0	10.0
	Laboratory Trailer	15.0	15.0	15.0	15.0	15.0
	Soot Blowers	19.0	19.0	19.0	19.0	19.0
	Sub-Total — Maintenance Equipment	44.0	44.0	44.0	44.0	44.0
Sludge Handling Equipment	Scrubber Effluent System (Tanks with Mixers, Conveyors and Pumps)	66.0	66.8	44.8	66.8	22.8
	Clarifiers (Tanks with Mechanisms and Underflow Pumps)	194.0	130.2	130.2	65.2	65.2
	Process Water System (Tanks with Mixers, Pumps)	58.7	39.6	39.6	19.9	19.9
	Filters (and Centrifuge)	135.7	67.4	67.4	33.8	33.8
	Recording Scales	19.7	9.8	9.8	5.0	5.0
	Conveyors	35.1	25.4	25.4	13.3	13.3
	Filtrate Return Pumps	7.5	3.8	3.8	2.0	2.0
	Test Settling Tank and Pump	8.3	----	----	----	----
	Water Softening Equipment	6.0	6.0	6.0	6.0	6.0
	Sub-Total — Sludge Handling Equipment	531.0	349.0	327.0	212.0	168.0
Piping	C.S. Pipe with Natural Rubber Lining	257.6	196.0	186.0	160.8	139.3
	Valves	94.6	71.0	66.0	47.3	37.9
	Steam Tracing	56.3	43.7	43.7	38.0	29.3
	Insulation	68.2	51.4	48.4	44.3	34.1
	Hangers, Supports and Misc.	36.9	31.0	29.5	24.8	20.9
	Testing and Inspection	11.4	8.9	8.4	7.8	6.5
	Sub-Total — Piping	525.0	402.0	382.0	323.0	268.0

Table 17-8 (Cont.)

COMPARISON OF PHASE I AND ALTERNATIVE DESIGN CAPITAL COSTS BREAKDOWN ($1000)

Item		Cost				
		Phase I	Alt. 1	Alt. 2	Alt. 3	Alt. 4
Electrical	Switchgear, Load Centers and Transformers	49.2	40.9	32.4	26.3	26.3
	Starters	16.5	15.2	14.2	10.9	8.7
	Distribution Panels and Misc. Equipment	23.0	20.9	19.9	15.5	13.8
	Conduit	250.6	234.2	231.2	208.4	130.5
	Wire and Cable	75.0	69.6	68.1	62.2	38.7
	Communications	4.7	4.4	4.4	2.9	2.4
	Grounding	5.0	4.7	4.5	3.7	2.7
	Lighting	60.0	53.1	52.3	43.6	30.9
	Sub-Total — Electrical	484.0	443.0	427.0	373.0	254.0
Instrumentation	Main Control Board with Instruments	8.9	6.9	6.4	5.2	4.2
	Local Panel Boards with Instruments	25.0	20.0	18.0	15.0	12.0
	Field Mounted Instruments	168.4	134.6	124.6	90.0	85.0
	Instrument Piping	91.0	70.3	62.8	46.8	36.8
	Instrument Tubing	42.0	33.2	30.2	22.2	22.2
	Line Testing	10.5	8.3	7.3	5.4	5.4
	Control Valves	53.4	42.7	37.7	26.7	26.7
	Chromatographs	26.2	26.2	26.2	17.5	17.5
	Chemical Analyzers	46.0	47.2	47.2	23.6	23.6
	Auto Analyzer	20.6	20.6	20.6	20.6	20.6
	Data Acquisition System	102.0	102.0	102.0	82.0	80.0
	Trailer	9.0	9.0	9.0	9.0	9.0
	Sub-Total — Instrumentation	603.0	521.0	492.0	364.0	343.0

Table 17-8 (Cont.)

COMPARISON OF PHASE I AND ALTERNATIVE DESIGN CAPITAL COSTS BREAKDOWN ($1000)

Item		Cost				
		Phase I	Alt. 1	Alt. 2	Alt. 3	Alt. 4
Start-Up	Equipment and Systems Check Out - Cold	52.0	54.0	50.0	45.0	43.0
	Sub-Total — Start-Up	52.0	54.0	50.0	45.0	43.0
	Total Field Cost	3595.0	2861.0	2613.0	2274.0	1740.0
Other Costs	Engineering	663.0	646.0	612.0	544.0	459.0
	Home Office	187.0	181.0	172.0	152.0	129.0
	Contingency	445.0	368.0	336.0	297.0	232.0
	Fee	255.0	209.0	192.0	170.0	133.0
	Escalation	205.0	155.0	145.0	123.0	97.0
	Total Other Costs	1755.0	1559.0	1457.0	1286.0	1050.0
Total Constructed Cost		5350.0	4420.0	4070.0	3560.0	2790.0
Savings over Phase I Design		----	930.0	1280.0	1790.0	2560.0
Adjustment of Alt. 2 by Adding Centrifuge, Gas Reheater, and Induced-Draft Fan				80.0		
Revised Total Construction Cost				4150.0		
Revised Savings over Phase I Design				1200.0		

Table 17-9

COMPARISON OF PHASE I AND ALTERNATIVE DESIGN RESTORATION COSTS SUMMARY ($1000)

Item		Cost				
		Phase I	Alt. 1	Alt. 2	Alt. 3	Alt. 4
Field Costs	Main Distribution Duct	31	25	25	17	17
	Flue Gas System	249	200	170	176	93
	Clarifiers and Related Equipment	270	203	203	150	126
	Filter Building Equipment	36	24	24	15	16
	Filter Building	14	12	12	7	8
	Additive Handling System	30	30	30	30	32
	Control Room Instrumentation	3	3	3	2	2
	Test Equipment	9	9	9	6	6
	Total Field Cost	642	506	476	403	300
Material Salvage		(400)	(290)	(250)	(200)	(140)
Other Costs	Engineering	--	--	--	--	--
	Home Office	28	24	24	22	20
	Contingency	130	100	100	88	63
	Fee	40	33	30	27	22
	Escalation	160	127	120	100	85
	Total Other Costs	358	284	274	237	190
Total Restoration Cost		600	500	500	440	350
Savings over Phase I Design		---	100	100	160	250

Table 17-9 (Cont.)

COMPARISON OF PHASE I AND ALTERNATIVE DESIGN RESTORATION COSTS BREAKDOWN ($1000)

Item		Cost				
		Phase I	Alt. 1	Alt. 2	Alt. 3	Alt. 4
Main Distribution Duct	Ductwork with Insulation	19.6	15.2	15.2	9.8	9.8
	Dampers and Expansion Joints	0.6	0.6	0.6	0.3	0.3
	Slide Gate Assemblies	2.4	2.0	2.0	1.5	1.5
	Miscellaneous Electrical	3.6	2.8	2.8	1.8	1.8
	Miscellaneous Instrumentation	2.4	2.0	2.0	1.2	1.2
	Reinstall Duct to Air Heater	2.4	2.4	2.4	2.4	2.4
	Sub-Total – Main Distribution Duct	31.0	25.0	25.0	17.0	17.0
Flue Gas System	Branch Ducts with Insulation	57.6	50.0	40.0	40.0	20.0
	Dampers and Expansion Joints	4.2	4.2	3.0	4.2	1.5
	Scrubbers	15.6	15.6	10.4	15.6	5.4
	Reheaters	6.6	4.4	3.3	2.2	2.3
	Induced Draft Fans	9.6	6.4	4.8	3.2	3.3
	Stacks	27.0	12.0	12.0	9.0	9.4
	Scrubber Effluent System (Tanks with Mixers, Conveyors, Pumps)	7.8	7.8	5.2	7.8	2.7
	Platforms and Supports	13.5	12.0	10.0	10.0	5.4
	Miscellaneous Electrical	82.5	66.2	62.5	64.0	33.0
	Miscellaneous Instrumentation	24.6	21.4	18.8	20.0	10.0
	Sub-Total – Flue Gas System	249.0	200.0	170.0	176.0	93.0

Table 17-9 (Cont.)

COMPARISON OF PHASE I AND ALTERNATIVE DESIGN RESTORATION COSTS BREAKDOWN ($1000)

	Item	Cost				
		Phase I	Alt. 1	Alt. 2	Alt. 3	Alt. 4
Clarifier and Related Equipment	Clarifiers (Tanks with Mechanisms, Underflow Pumps	23.5	16.0	16.0	8.0	8.2
	Process Water System (Tanks with Mixers, Pumps)	8.8	6.0	6.0	3.0	3.1
	Piping and Pipeway	198.5	150.0	150.0	120.0	100.0
	Miscellaneous Electrical	22.8	18.0	18.0	10.0	8.0
	Miscellaneous Instrumentation	16.4	13.0	13.0	9.0	6.7
	Sub-Total — Clarifiers and Related Equipment	270.0	203.0	203.0	150.0	126.0
Filter Building Equipment	Filters and Centrifuge	8.8	4.4	4.4	2.2	2.4
	Recording Scales	1.6	0.8	0.8	0.4	0.4
	Conveyors	11.0	7.5	7.5	5.0	5.4
	Filtrate Return Pumps	0.8	0.4	0.4	0.2	0.2
	Test Settling Tank and Pump	0.8	----	----	----	----
	Water Softening Equipment	2.4	2.4	2.4	2.4	2.6
	Miscellaneous Electrical and Instrumentation	10.6	8.5	8.5	4.8	5.0
	Sub-Total — Filter Building Equipment	36.0	24.0	24.0	15.0	16.0
Filter Building	Building Shell	2.8	2.2	2.2	1.6	2.0
	Heating Equipment	0.5	0.5	0.5	0.3	0.3
	Miscellaneous Electrical	5.9	5.2	5.2	2.5	2.8
	Foundation Concrete	4.8	4.1	4.1	2.6	2.9
	Sub-Total — Filter Building	14.0	12.0	12.0	7.0	8.0

Table 17-9 (Cont.)

COMPARISON OF PHASE I AND ALTERNATIVE DESIGN RESTORATION COSTS BREAKDOWN ($1000)

Item		Cost				
		Phase I	Alt. 1	Alt. 2	Alt. 3	Alt. 4
Additive Handling System	Limestone Feeding Area	12.0	12.0	12.0	12.0	12.8
	Bunker Partitions	13.0	13.0	13.0	13.0	13.8
	Gravimetric Feeder and Pipe	5.0	5.0	5.0	5.0	5.4
	Sub-Total — Additive Handling System	30.0	30.0	30.0	30.0	32.0
	Control Room Instrumentation	3.0	3.0	3.0	2.0	2.0
	Test Equipment	9.0	9.0	9.0	6.0	6.0
Total Field Cost		642.0	506.0	476.0	403.0	300.0
Material Salvage		(400.0)	(290.0)	(250.0)	(200.0)	(140.0)
Other Costs	Engineering	----	----	----	----	----
	Home Office	28.0	24.0	24.0	22.0	20.0
	Contingency	130.0	100.0	100.0	88.0	63.0
	Fee	40.0	33.0	33.0	27.0	22.0
	Escalation	160.0	127.0	120.0	100.0	85.0
	Total Other Costs	358.0	284.0	274.0	237.0	190.0
Total Restoration Cost		600.0	500.0	500.0	440.0	350.0
Savings over Phase I Design		----	100.0	100.0	160.0	250.0

Table 17-10

COMPARISON OF PHASE I AND ALTERNATIVE DESIGN OPERATING COSTS ($1000)

Item		Cost				
		Phase I	Alt. 1	Alt. 2	Alt. 3	Alt. 4
Chemicals	Limestone	303.0	396.0	303.0	475.0	303.0
	Miscellaneous	8.0	10.5	8.0	12.5	8.0
	Subtotal Chem.	311.0	406.5	311.0	487.5	311.0
Utilities	Coal	34.5	45.0	34.5	54.0	34.5
	Steam	51.1	12.5	10.0	14.9	10.0
	Natural Gas	56.8	148.8	113.6	88.5	56.8
	Electricity	46.0	40.2	30.8	23.8	15.4
	Water	20.6	18.0	13.7	10.8	6.9
	Subtotal Util.	209.0	264.5	202.6	192.0	123.6
Labor	Operations	450.0	450.0	350.0	370.0	236.0
	Bechtel Eng.	160.0	210.0	160.0	250.0	160.0
	Test Manager	45.0	59.0	45.0	71.0	45.0
	Asst. Manager	33.6	43.5	33.6	52.0	33.6
	Maintenance	346.0	415.0	318.8	450.0	288.0
	Laboratory	106.0	139.0	106.0	165.0	106.0
	Clerical	25.0	32.8	25.0	39.0	25.0
	Computer	10.0	13.1	10.0	15.6	10.0
	Subtotal Labor	1175.6	1362.4	1048.4	1412.6	903.6
Misc.	Supplies, Etc.	20.0	26.2	20.0	31.0	20.0
	Water Disposal	87.0	114.0	87.0	136.0	87.0
	Subtotal Misc.	107.0	140.2	107.0	167.0	107.0
Total less Contingency and Fee		1802.6	2173.6	1670.0	2259.1	1445.2
Contingency		360.3	434.4	334.0	451.9	289.8
Fee		151.1	182.0	140.0	190.0	121.0
TOTAL OPERATING COSTS		2314.0	2790.0	2144.0	2901.0	1856.0

Appendix A

EQUIPMENT LIST

A. 1 MECHANICAL AND STRUCTURAL

Additive Handling		Equip No.
Feed Hopper	1 - 12' x 12' x 8'7" 1/4" pl. c. s. w/bar grating	D-1
Hopper Discharge Gate	1 - Rack & Pinion 20" x 20"	D-2
Additive Storage Hopper Sump Pump	1 - 2-hp non-clog, vertical, centrifugal, 50 gpm, 40 TDH, 1750 rpm	G-1
Redler Conveyor/ Elevator	1 - "L" type; 60 incline, 160 tons/hr. 19" wide x 60' long; complete w/driver inlet and discharge heads	T-1
Conveyor Discharge Chute	1 - 19" x 36" x 10' long 1/4" pl. c. s.	M-1
Bunker Partitions (Fabricated Alterations to Existing Bunker)	2 - 22' x 44' - 1/4" pl. c. s. w/stiff. & gunited	M-2 M-3
	1 - 14' x 13' - 1/4" pl. c. s. w/stiff. & gunited	M-4
	1 - 14' x 17' - 1/4" pl. c. s. w/stiff. & gunited	M-5
	1 - 14' x 18' - 1/4" pl. c. s. w/stiff. & gunited	M-6
	1 - 10' x 14' - 1/4" pl. c. s. lined w/s. s.	M-7

Additive Handling (cont'd)

		Equip No.
Bunker Gate Assy.	1 - Rack & Pinion 20" x 20"	D-3
Discharge Chute	1 - dual compartment 3' x 6' x 7'6" s. s. plate	M-8
Discharge Pipe	1 - 22" dia. x 12' s. s.	L-1
Discharge Pipe Junction	1 - 22" dia. x 10' s. s. (2-Branch "Y")	L-2
Gravimetric Feeder	1 - 15 ton/hr capacity - standard unit	T-2
Front-End Loader	1 - 3 cubic yard capacity rubber-tired loader for additive handling and solid disposal	T-3

Flue Gas System

Slide Gate Assemblies	5 - 5'4" x 8'4" - 1/4" pl. c. s. w/stiff. guides and rubber seals	M-9 M-13
Gate Actuating Motors	5 - 2 hp motors(Limitorque)	K-1 K-5
Main By-Pass Duct	1 - 3'9" x 25' high sloping to 6' high in 96' of length. 3/16" galv. and insul. w/2" asbestos and weather-proofed w/stiffeners and supports	M-14
Expansion Joint	1 - 3'9" x 25' Double Bellows c. s.	M-15
Scrubber Inlet Ducts	3 - 5' x 6' x 110' long, 3/16" galv. w/insul. stiffeners and supports as required	M-16 M-17 M-18
Scrubber Outlet Ducts	3 - 5' x 6' x 60', 110' x 100' long 3/16" galv. w/insul. stiffeners and supports as required	M-19 M-20 M-21
Stacks	3 - 5' dia. at exit; 10' dia. at base x 150' high c. s. gunited,	F-1 F-2 F-3

Plant No. 100		Equip No.
Venturi Scrubber	1 - 100,000 CFM @250°F 14.315 psia, 316-L s.s.	C-101
Gas Fired Flue	1 - Multiple gas burner direct heater nat. gas @30 psig 150°F ΔT 11,700,000 Btu/hr.	E-101
Induced Draft Fan w/Driver	1 - 94,000 cfm @275°F, 35" w.g. static pressure, 800 hp, 1200 rpm	K-101
Reheater Combustion Air Fan w/Driver	1 - 2700 cfm 20" w.g. static pressure, centrifugal w/25 hp motor	K-102
Scrubber Effluent Hold Tank	1 - 15' dia. x 8' high rubber lined c.s.	D-101
Clarifier	1 - 60' dia. x 15' high w/launders rubber lined walls, c.s., clay and sheet metal bottom	D-102
Process Water Hold Tank	1 - 15' dia. x 10' rubber lined, c.s.	D-103
Clarifier Underflow Vacuum Filter	1 - 6' dia. x 8' long belt drum filter and 50 hp vacuum pump, drum drive and agitator w/motors	Y-101
Scrubber Effluent Tank Mixer	1 - 2 hp variable speed motor, s.s. shaft and impeller	Y-103
Process Water Hold Tank Mixer	1 - 7 1/2 hp motor, s.s. shaft and impeller	Y-104
Clarifier Rake and Driver	1 - 3 hp drive for unit to be used in 60' dia. tank 18' deep in the center, s.s. for all submerged surfaces	Y-105

Plant No. 100 (cont'd)		Equip. No.
Scrubber Effluent Pumps w/Drivers	2 - 1600 gpm, 85' TDH, 50 hp centrifugal pumps to handle 10% slurry, Alloy 20 case and impeller	G-101 G-102
Clarifier Underflow Pumps w/Drivers	2 - 75 gpm, TDH, 5 hp centrifugal pumps to handle 30% slurry, Alloy 20 case and impeller	G-103 G-104
Scrubber Process Water Recirc. Pumps w/Drivers	2 - 1600 gpm, 85 TDH, 50 hp centrifugal pumps to handle 10% slurries, Alloy 20 case and impeller	G-105 G-106
Filtrate Return Pump w/Driver	1 - 200 gpm, 100' TDH, 7 1/2 hp centrifugal pump, Alloy 20 case and impeller	G-109
Filter Solids Conveyor w/Scale	1 - 35° troughed belt conveyor 14" wide x 24' long, 15 tons/hr capacity, 3 hp motor	T-101
Screw Conveyor and Inclined Scraper Unit w/Driver	12" screw w/ 1/2 hp drive motor	T-105

Plant No. 200

TCA Scrubber	1 - 100,000 CFM @275°F 14.315 psia, 316-L s.s.	C-201
Steam Coil Flue Gas Reheater	1 - Finned tube (4 fins/inch) c.s. Heat Exchanger for 11,700,000 Btu/hr @150°F ΔT	E-201
Induced Draft Fan w/Driver	1 - 94,000 c/m/ @275°F, 35"w.g. static pressure, 800 hp, 1200 rpm	K-201
Scrubber Effluent Hold Tank	1 - 15' dia. x 8' high rubber lined c.s.	D-201

Plant No. 200 (cont'd)		Equip. No.
Clarifier	1 - 60' dia. x 15' high w/launders rubber lined c. s. walls, clay and sheet metal bottom	D-202
Process Water Hold Tank	1 - 15' dia. x 10' rubber lined c. s.	D-203
Test Settling Tank	1 - 10' wide x 50' long x 6' deep rubber lined c. s.	D-204
Clarifier Underflow Vacuum Filter	1 - 6' dia. x 8' long belt drum filter and 50 hp vacuum pump, drum drive and agitator w/motors	Y-201
Clarifier Underflow Centrifuge w/Driver	1 - 24" x 60" solid bowl centrifuge to handle 70 gpm slurry sp. gr. 1. 3 and 30% solids by weight, 75 hp motor	Y-202
Scrubber Effluent Hold Tank Mixer	1 - 2 hp variable speed motor, s. s. shaft and impeller	Y-203
Process Water Hold Tank Mixer	1 - 7 1/2 hp motor, s. s. shaft and impeller	Y-204
Clarifier Rake and Driver	1 - 3 hp drive for unit to be used in 60' dia. tank 18' deep in the center, s. s. for all submerged surfaces	Y-205
Scrubber Effluent Pumps w/Drivers	2 - 1600 gpm, 85' TDH, 50 hp, centrifugal pumps to handle 10% slurry, Alloy 20 case and impeller	G-201 G-202
Clarifier Underflow Pumps w/Drivers	2 - 75 gpm, 80' TDH, 5 hp centrifugal pumps to handle 30% slurry, Alloy 20 case and impeller	G-203 G-204
Scrubber Process Water Recirc. Pump w/Drivers	2 - 1600 gpm, 85' TDH, 50 hp centrifugal pumps to handle 10% slurry, Alloy 20 case and impeller	G-205 G-206

Plant No. 200 (cont'd)		Equip. No.
Condensate Return Pump w/Driver	1 - 10 gpm, 100' TDH, 1/2 hp centrifugal pump, Alloy 20 case and impeller & storage tank 3' Dia. x 5' c. s.	G-207
Settling Tank Recirc. Pump w/Driver	1 - 50 gpm, 60 TDH, 1 hp centrifugal pump, c. s. case and impeller	G-208
Filtrate Return Pump w/Driver	1 - 200 gpm, 100' TDH, 7 1/2 hp centrifugal pump, Alloy 20 case and impeller	G-209
Centrate Return Pump w/Driver	1 - 200 gpm, 80' TDH, 5 hp centrifugal pump, Alloy 20 case and impeller	G-210
Filter Solids Conveyor w/Scale	1 - 35° troughed belt conveyor 14" wide x 24' long 15 tons/hr capacity, 3 hp motor	T-203
Centrifuge Solids Conveyor w/Scale	1 - 35° troughed belt conveyor 14" wide x 20' long 15 tons/hr capacity, 3 hp motor	T-204
Screw Conveyor and Inclined Scraper Unit w/Driver	1 - 12" screw w/ 1/2 hp drive motor	T-205
Collecting and Stacking Conveyor w/Driver	1 - 12" wide conveyor belt w/3" corrugated sides, "L" type, 17° incline x 133' long, 3 hp driver	T-206

Plant No. 300		Equip. No.
Flooded Bed Scrubber	1 - 100,000 CFM @275°F 14.315 psia, 316-L s. s.	C-301
Impingement Baffle Plate Scrubber Internals	To fit in 10' x 20' shell, s. s. construction, includes two impingement baffle plates and one demister and wetted wall inlet section	C-301A

Plant No. 300 (cont'd)		Equip. No.
Regenerative Flue Gas Cooler	1 - Finned tube (4 fins/inch) c. s. Heat Exchanger for 4,000,000 Btu/hr @ 60°F ΔT	E-301
Flue Gas Reheater	1 - Finned tube (4 fins/inch) c. s., Heat Exchanger for 4,000,000 Btu/hr @60° F ΔT	E-302
Induced Draft Fan w/Driver	1 - 94,000 cfm @275°, 35" w.g. static pressure, 800 hp, 1200 rpm	K-301
Scrubber Effluent Hold Tank	1 - 15' dia. x 8' high rubber lined c. s.	D-301
Clarifier	1 - 60" dia. x 15' high w/launders rubber lined c. s. walls, clay and sheet metal bottom	D-302
Process Water Hold Tank	1 - 15' dia. x 10' rubber lined c. s.	D-303
Surge Tank	1 - 4' dia. x 5' c. s.	D-304
Clarifier Underflow Vacuum Filter	1 - 6' dia. x 8' long belt drum filter and 50 hp vacuum pump, drum drive and agitator w/motors	Y-301
Scrubber Effluent Hold Tank Mixer	1 - 2 hp variable speed motor, s. s. shaft and impeller	Y-303
Process Water Hold Tank Mixer	1 - 7 1/2 hp motor, s. s. shaft and impeller	Y-304
Clarifier Rake and Driver	1 - 3 hp drive for unit to be used in 60' fia. tank 18' deep in the center, s. s. for all submerged surfaces	Y-305
Scrubber Effluent Pumps w/Drivers	2 - 1600 gpm, 85' TDH, 50 hp, centrifugal pumps to handle 10% slurry, Alloy 20 case and impeller	G-301 G-302

Plant No. 300 (cont'd)		Equip. No.
Clarifier Underflow Pumps w/Drivers	2 - 75 gpm, 80' TDH, 5 hp centrifugal pumps to handle 30% slurry, Alloy 20 case and impeller	G-303 G-304
Scrubber Process Water Recirc. Pumps w/Drivers	2 - 1600 gpm, 85' TDH, 50 hp centrifugal pumps to handle 10% slurry, Alloy 20 case and impeller	G-305 G-306
Regenerative Water Recirc. Pump w/Driver	1 - 80 gpm, 80' TDH, 2 hp, centrifugal pump, c. s. case and impeller	G-307
Filtrate Return Pump w/Driver	1 - 200 gpm, 100' TDH, 7 1/2 hp centrifugal pump, Alloy 20 case and impeller	G-309
Filter Solids Conveyor w/Scale	1 - 35° troughed belt conveyor 14" wide x 24' long 15 tons/hr capacity, 3 hp motor	T-301
Screw Conveyor and Inclined Scraper Unit w/Driver	1 - 12" screw w/ 1/2 hp drive motor	T-305

Water Softening System

Chemicals Mixing Tank	1 - 5' dia. x 5' rubber lined c. s.	D-401
Mixer for Chemicals Mixing Tank	1 - 2 hp drive. s. s. shaft and impeller	Y-401
Chemicals Feed Pump w/Driver	1 - 100 gpm, 50 TDH, 2 hp rubber lined centrifugal pump	G-401
Volumetric Feed Pump w/Driver	1 - 1 gpm, 1/4 hp, positive displacement pump	G-402
Solids Feeders w/Drivers	2 - 1" Volumetric screw, 1/4 hp feeders, capacity for 1 cu. ft. /hr.	T-401 T-402

Filter Building
Heating & Ventilating

		Equip. No.
Unit Heaters	6 - American Air Filters, Model HVE-3. One-row coil Model DT (8 fins/inch) Minimum 850 cfm.	
Gravity Roof Ventilators	4 - Moffitt Industrial Round Cavity Ventilators, Model 2096, 48" diameter	
Louvers	10 - Airolite #663 louvers, 4' wide x 5' high, operating type, steel adjustable blades, w/insect screens	

A. 2 ELECTRICAL

Power Load Center	1 - Power Load Center incl.	P-1
	1 - 1000 KVA, 2.4 KV/480 - 277V 3 phase, dry-type transformer	
	4 - Units of 2.4 KV. Metal-clad Switchgear, incl. Ammeter, current transformers voltage and overcurrent relays & power circuit breaker (stored energy)	
	1 - Incoming and Metering Unit: - incl. kilowatt/hour meter, Voltmeter, Ammeter, Ammeter switch, current and potential transformers	
Main Distribution Panel	1 - Main Distribution Panel, NEMA-12 incl. molded case circuit breakers - type TJK and THEF	P-2
	3 - 600 - 3 P	
Intermediate Distribution Panels	3 - Distribution Panels, NEMA-12 incl. molded case circuit breakers type TJK and THEF 4 - 100 A - 3P 4 - 225 A - 3P	P-3 P-4 P-5

		Equip No.
Local Distribution Panels	5 - Local Distribution Panels, NEMA-4 incl. molded case circuit breakers - type TJK and THEF 6 - 100 A - 3P	P-6 to P-10
Local Distribution Panels	3 - Distribution Panels, NEMA-12 incl. molded case circuit breakers - type TJK and THEF 10 - 100 A - 3P	P-11 P-12 P-13
Local Distribution Panels	2 - Distribution Panels, NEMA-12 incl. molded case circuit breakers - type TJK and THEF 8 - 100A - 3 P	P-14 P-15
Local Distribution Panel	1 - Distribution Panel, NEMA-12 incl. molded case circuit breakers - type TJK and THEF 8 - 100 A - 3P 1 - 225 A - 3P	P-16
Local Distribution Panels	4 - Distribution Panels, NEMA-12 incl. molded case circuit breakers 12 - 20 A - 1P	P-17 to P-20
A. C. Magnetic Full Voltage Motor Starters	600 volt, three overload relays, start-stop push buttons in cover NEMA - 4 enclosure, FVNR 13 - size 3 1 - size 2 20 - size 1 NEMA - 12 enclosure FVNR 1 - size 4 3 - size 3 6 - size 1 NEMA - 4 enclosure, FVR 5 - size 1	P-21

		Equip. No.
Transformer	2 - 10 KVA, 480/120 - 208 Volt Single Phase, dry-type	P-22 P-23
Transformer	3 - 25 KVA, 480/120 - 208 Volt Single Phase, dry-type	P-24 P-25 P-26
Metering Unit	1 - Panel, NEMA-4 incl. 3 current Transformers 1 - 3 element Killowatt/hr meter	P-27
Building and Yard Lighting	1 - system incl. 30 - hot-filament low-bay units, 500 W 15 - mercury vapor color improved wide angle, 1000 watt units 50 - RLM, 300 watt units	P-28

Appendix B

GENERAL INSTRUMENT SPECIFICATIONS

B.1 PURPOSE AND SCOPE

The purpose of this specification is to define the general requirements for instruments and control equipment.

B.2 GENERAL SPECIFICATIONS

B.2.1 Specifications

Instruments will be specified on Contractor's standard forms or by written description.

B.2.2 Installation Drawings and Schedules

Installation drawings and schedules will be prepared by the Contractor to show instrument location, piping, wiring, service, etc., to insure proper instrument installation.

B.2.3 Electrical Requirements

All instruments located in the process area will be furnished to meet the electrical classification of that area. All instruments located in the control house will be general purpose.

B.2.4 Pneumatic Requirements

All controllers, indicators, and transmitters shown as pneumatic instruments will operate on a 3 to 15 psig air signal for transmission and control. Higher air pressure may be used for actuating final control elements.

B.2.5 Electronic Instruments

Where shown as such, controllers, recorders, indicators, and auxiliary devices will be electronic type instruments utilizing an electric signal for transmission and control.

B.3 INSTRUMENT REQUIREMENTS

B.3.1 Weatherproofing

All instruments exposed to the weather will be moisture- and dustproof with no exchange of atmosphere, except in Class 1, Group D, Division 1 areas.

B.3.2 Measurement Units

The following units will apply for flow measurement:

Process Liquids - gpm
Vapors - standard cubic feet per hour *
Steam - pounds per hour
Utility Air - standard cubic feet per minute *
Utility Water - gpm

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* Computed at 14.7 psia barometric pressure

B.4 PANEL-MOUNTED INSTRUMENTS

B.4.1 Miniature Controllers

Miniature controllers will have manual transfer switches. All panel-mounted controllers shall be plug-in type. All controllers will normally have reset. Temperature controllers will normally have reset and derivative action. Flow controllers will have fast reset. All controllers will have a minimum proportional band adjustment of 0 to 200%.

B.4.2 Alarms

Alarm circuits will be normally closed. Shutdown circuits will be normally open circuits. Alarms located on the control-room panel will have flashing lights and audible alarm. TEST and ACKNOWLEDGE pushbuttons will be provided.

B.4.3 Pressure Switches

Pressure switches used in conjunction with transmitted air signals will be SPDT. Pressure elements will be brass or bronze. Switches will have adjustable set point and will be suitable for the electrical classification of that area.

B.5 GENERAL REQUIREMENTS - FLOW INSTRUMENTS

B.5.1 Meter Runs

For piping design purpose, meter runs will conform to Bechtel Standard Drawings J-F-0101 through J-F-0108, based on an orifice-to-pipe diameter ratio of 0.70. Longer meter runs will be provided for custody transfer meters. The minimum size standard meter run diameter will be 1-1/2 inches. For meter runs of less than 1-1/2 inches, calibrated meter runs will be considered. If necessary, meter run diameter will be increased in order not to exceed maximum ratio requirement.

B.5.2 Meter Ranges

Meter ranges will, wherever practical, be 100 inches H_2O. Higher or lower ranges may be used, if required.

B.5.3 Metering Rangeability for Orifice Type Meters

Metering range shall not exceed 3.5 to 1. Design flow shall be at approximately the mid-point on the scale.

B.5.4 Primary Flow Elements

a. Orifice Plates

Concentric orifice plates with flange taps will be used; wherever practical, d/D ratio of 0.2 to 0.75 will be used.

b. Flow Tubes of Venturis

Flow tubes of the low-permanent-pressure-loss type will be used on the inlet flue gas to each scrubber.

c. Flow Nozzles

Flow nozzles may be used to improve accuracy, protect against erosion, and in special applications.

B.5.5 Meter Types

All flow meters will be the dry type.

B.5.6 Orifice Plates and Orifice Calculations

a. Orifice plates will, in general, be per Bechtel standard drawings. Plate material will be Type 304 stainless steel. Plate may be made of other material if required for corrosion resistance.

b. Orifice calculations will be run on a computer wherever practical. The Foxboro rule may be used in special cases. The instrument vendor of the primary flow device will be required to furnish calculations.

c. Orifice bore will be rounded to nearest one thousandth of an inch.

B. 5. 7 Differential Pressure Transmitters

Differential pressure transmitters will be of the force balance type, with 250 minimum psi carbon steel body, 316 stainless steel diaphragm, 1/2-inch NPT process connection, universal pipe mounting bracket, and provision for adjustment of range.

B. 6 PRESSURE INSTRUMENTS

B. 6. 1. Range and Pressure Element

All pressure instruments will be specified with a range approximately twice operating pressure, except where process conditions dictate otherwise. Pressure elements will be of suitable alloys, if required for corrosion resistance.

B. 6. 2 Viscous and Corrosive Fluids

All instruments used for handling viscous or corrosive materials will be sealed. Seals may be the liquid type employing seal pots, or the chemical type employing a diaphragm of suitable material and a silicon oil fill between the diaphragm and the pressure element of the instrument. Diaphragm seals are preferred for applications within the temperature limitations of this type of seal. Capillary tubing, if required, will be stainless steel 1/8-inch O. D. or be protected by a stainless steel spiral-wound armor. Temperature limitations on the use of diaphragm seals will be specifically considered.

B.6.3 Transmitters

Electronic transmitters will be of the nonindicating type. Transmitters will be of the force-balance type. Process connection will be 1/2-inch NPT, and instruments will be equipped with pipemounting yoke. Transmitter output tubing will be provided with a plugged tee only, for installation of a calibrating pressure gauge.

B.6.4 Pressure Gauges and Pneumatic Receiver Gauges

Pressure gauges will be 4-1/2 inch diameter, with 1/2-inch NPT bottom connection, phenol turret case, and white laminated phenol dials with black graduations. Gauges will have blowout disc and safety glass; movement may be either rotary geared stainless steel or cam and roller type. Accuracy will be 1/2 of 1% minimum. Receiver guages will have bronze extra-wide bourdon tubes with brass socket and tip and 1/4-inch NPT bottom connection. Case, size, etc., will be the same as for pressure gauges. Bourdon tube, socket, and tip will be made of suitable alloys for the specific services.

B.6.5 Pressure Switches and Differential Pressure Switches

Pressure switches will be DPDT or SPDT with adjustable set-point and fixed or adjustable differential as required, and will be suitable for the electrical classification of the area. Pressure element materials will be suitable for the service.

B.7 THERMAL INSTRUMENTS AND TRANSMITTERS

B.7.1 Blind Transmitters -- Electronic Type

Blind temperature transmitters will be of the electronic resistance transducer type which converts input signal to a proportionate electronic output as required. Narrow-span fixed-range type with upscale burnout feature will be used for control applications.

B.7.2 Temperature Switches and Differential Temperature Switches

Temperature switches will be DPDT or SPDT and will be suitable for the electrical classification of the area. A thermal system may be liquid-filled with stainless steel bulb, capillary, and armor. It will include either union connection or a bimetallic type switch. Temperature setting and differential adjustment will be external to the switch housing whenever a suitable electrical rating can be met.

B.7.3 Thermowells

Thermowells will be a minimum of 304 stainless steel or other materials to suit service conditions. Screwed or flanged wells will be provided to suit process considerations, with 1-inch-minimum connections. Bore will be as required to accommodate insertion of bulb or thermocouple with good grounding. Test wells will be equipped with plugs and drain of brass or other suitable material to suit atmospheric conditions. Thermowells for dial thermometers will be furnished with the thermometer and will have 1-inch NPT connections.

B.7.4 Dial Type Thermometers

Dial thermometers may be either bimetallic or mercury-filled type. Dial size will be 5 inches in diameter.

B.7.5 Thermocouples

Thermocouples will be of the gauge and material to suit temperature conditions.

B.7.6 Differential Pressure Level Transmitters

Differential pressure level transmitters will be in accordance with paragraph B.5.7, except that range will be suppressed so that the output signal from the transmitter will increase with increased level. Air-purged dip tubes will be used to keep solids out of the instruments.

B.8 RELIEF VALVES

B.8.1 Construction

Flanged relief valves will be of the enclosed-spring type, except for air and steam valves, which will be the bolted-bonnet, screwed-cap, full-nozzle type with stainless steel nozzle, disk, guide, and spindle, and cast carbon steel bodies. Alloy steel bodies or trim other than stainless steel may be used if required for the particular service. Body pressure ratings for all flanged valves will be of the same rating as for valve inlet flange. Lightweight bodies will not be acceptable. The area of flange discharge opening will not be less than four times the area of the valve seat. Screwed valves may have screwed bonnets and may be used where small orifice areas are required. Screwed valves will not be full-nozzle type.

B.8.2 Lifting Levers and Springs

Open lifting levers will be supplied on all valves used on piping and unfired pressure vessels for steam and air service. No lifting levers are required for process valves. Carbon steel springs will be supplied for valves in temperature service at 450 F and below. Tungsten steel springs will be supplied for valves in service above 450 F maximum relieving temperature. Other spring materials may be used, if required, for a particular service.

B.8.3 Pressure-Balanced Valves

Pressure-balanced valves with stainless steel bellows will conform to paragraphs B.8.1 and B.8.2. These valves will be used where varying back pressure exceeds 10 percent of the set pressures of the relief valve.

B.8.4 Code Stamp

The proper ASME Code stamp will appear on all valves used to protect pressure vessels -- "UV" or "V" as required by the code.

B.9 SOLENOID VALVES

Solenoid-operated valves will be of the continuous-duty type equipped with encapsulated coils and will meet the area electrical classification. Latch-type reset will be incorporated where required.

B.10 DIAPHRAGM-OPERATED GLOBE TYPE CONTROL VALVES

B.10.1 General Construction

Diaphragm-operated control valves will be of high-lift, top-and-bottom-guided design with removable seat rings. Minimum valve body size will be one inch. Valves with reduced trim in one-inch body size may be top guided only.

All valves will have bolted gland-type stuffing boxes with Teflon or Teflon asbestos packing within the temperature limits of this material. For other special services above these limits, Crane Superseal, Durametallic, etc., will be provided to meet service conditions. All valves will be equipped with travel indicator.

Diaphragm housings will be of the multiple-bolted type, using pressed steel. Valve yokes will be cast iron.

Valve bonnets and blinds will be bolted with retained-type gaskets, suitable for temperatures as indicated on data sheets.

All inner valves will be of the equal-percentage type with the exception of butterfly valves and special cases where process conditions dictate otherwise. Double-seated valves will be used wherever possible. Single-seated valves will be used where positive shutoff is required, unless other characteristics prohibit this.

Minimum standard valve trim will be used as follows:

Valve Stem	316 or 304 stainless steel
Guides	440 hardened stainless steel
Inner Valve	316 stainless steel
Seat Rings	316 stainless steel

Valves up to and including 1-1/2 inches may be screwed, piping specification permitting. All other valve bodies will be flanged, with 300 psig minimum rating for all steel valves.

B.10.2 Extension Bonnets

Radiating fin bonnets will be used on all valves handling material above 450 F.

B.10.3 Positioners

Valve positioners will be of the side-mounted direct-acting type with three gauges and bypass. Positioners will be supplied on all modulating valves in the following service:

- All temperature control valves, except for pressure balanced type
- Valves 6 inches and larger, and all butterfly valves
- Valves with pressure drops of 150 psig or more
- All valves operating at 450 F or higher
- All single-seated valves with substantial port unbalance, where an increased pressure is required to the diaphragm operator
- Valves where solids may desposit on the stem, or where extra tight or deep stuffing boxes are required.

B.10.4 Valve Trim

Hardened Stellite facing will be used on the seating surface or valve plug and seat on all valves with a pressure drop of 150 psig or more, and on all on-off nonthrottling valves in steam service.

All valves in steam service will have hardened guiding surfaces of either Stellite, 440 C stainless steel, Colmonoy, or Armco 17-4 PH.

B.11 BUTTERFLY VALVES

All slurry control valves shall be wafer type butterfly valves 6 inches and larger with pressure drops of 5 pounds or less, if tight shutoff is not required. Valve body rating will follow line rating. Valve operators may be of the piston-operated type to provide higher torque if necessary. Side-mounted, continuously-connected handwheels will be provided where required. All applications for butterfly valves requiring tight shutoff will be specially considered.

B. 12 CONTROL-VALVE SIZING

All valves with linear flow characteristics will be sized on the basis of the normal flow not exceeding 75 percent of valve capacity.

All valves with percentage flow characteristics will be sized on the basis of the normal flow not exceeding 65 percent of capacity.

If maximum flows are known, 90 percent of capacity will be used for sizing.

B. 13 CONTROL-VALVE BLOCK AND BYPASS VALVES

Block and bypass valves for control valves will be provided where indicated on the Piping and Instrument Diagrams.

Block valves and bypass will be provided where inability to operate would endanger plant equipment or personnel.

B. 14 INSTRUMENT MOUNTING AND LOCATION

All field instruments will be mounted at grade on a platform. All field-mounted indication instruments will be mounted so that scale is 4' 6" above grade or platform, and will be located as close to primary connection as possible, consistent with instrument accessibility.

All instruments, except close-coupled pressure gauges and thermocouples in liquid or liquid-sealed service will be located below their process connection point, and connections will slope down to instrument at 1/4-inch per foot minimum wherever practicable.

Instruments in dry gas services may be located either above or below their process connection point.

Dial thermometers, pressure gauges, thermowells, etc., that are line-mounted will be plainly visible and accessible from grade or platform. Where excessive vibration of line or equipment is present, the instrument will be separately mounted.

B.15 PRIMARY INSTRUMENT CONNECTIONS

B.15.1 General Practices

All primary instrument connections will be shown on area piping drawings. Where piping specifications allow screwed or socket weld fittings, a 3000 pound minimum F.S. coupling will be used for pressure, differential pressure, level switches, and gauge glasses where a single gauge is required. Size of coupling for these services will be as follows:

Pressure and differential pressure	3/4 inch
Level switch	1 inch
Single gauge glass	3/4 inch

All temperature points on vessels will be 1-inch NPT screwed or 300-pound ASA flanged. No socket weld will be allowed.

All temperature points on process lines will be 1-inch NPT screwed or 1-1/2 inch flanged.

B.15.2 Primary Connections Nipple and Block Valve

Primary connection nipple will be Schedule 80 seamless steel minimum.

Block valves will be in accordance with individual piping specifications. Where piping specifications require socket-weld block valves, an F.S. adapter POE-TOE female will be socket-welded to the downstream side of the valve. Nipple and block valve sizes are indicated below:

Pressure and differential pressure	3/4- by 1/2-inch Swage nipple and 1/2-inch valve
Pressure test point	3/4- by 1/2-inch Swage nipple and 1/2-inch valve and plug
Temperature	None
Flow instruments	1/2-inch nipples and valves

B.16 INSTRUMENT PROCESS PIPING

B.16.1 Valves

All valves following the primary block valve and used for instrument piping will be in accordance with the instrument piping specifications. All conventional primary valves will be according to individual piping specifications.

B.16.2 Pipe, Tubing, and Fittings

All process instrument piping where pipe is required for meter manifolds will be Schedule 80 seamless steel and 3000-pound F.S. fitting minimum.

All other process instrument piping will consist of 1/2-inch-O.D. by 0.049-wall fully-annealed steel tubing. Tubing fittings will be of the compression type. Suitable alloys will be used where required against corrosion.

Piping for D/P line-mounted flow transmitters will have three valves, including orifice valves and equalizing valve. Meter piping for remote-mounted flow instruments, in addition to the orifice valves, will include a minimum of two block valves and a bypass.

Direct-connected pressure gauges and switches will have 1/2-inch vent or drain valves, as required by service.

Remote-mounted pressure instruments will have block valves and vents or drain plugs at the instrument.

Level instruments will have vent plugs and drain valves.

B.17 INSTRUMENT AIR SUPPLY

Instrument air-supply headers and branches will be in accordance with the applicable piping specification.

Air-supply connections to individual instruments will be 1/2-inch pipe with 1/2-inch block valve at the air headers and 1/4-inch gauge valve at the supply side of the instrument filter regulators. Connections from instrument filter regulators to instruments will be made with pneumatic tubing.

B.18 PNEUMATIC TUBING

Individual pneumatic tubing will be 1/4-inch-O.D. by 0.030-inch-wall copper tubing suitably supported.

Fittings for copper tubing will be of the compression type.

All instrument filter regulators supplying instruments that do not have an air-supply gauge will be equipped with a 2-inch, weatherproof gauge. Each field-mounted instrument that requires air will have a combination air-filter and regulator.

B.19 INSTRUMENT AND PIPING SUPPORTS

All instruments will be adequately supported to insure proper operation. Where pipe stanchion supports are required, they will be of 2-inch, Schedule 40 pipe. Where fittings are required, they will be of 150-pound M.I.

All instrument leads to vessels, lines, or equipment will be properly supported to relieve strain on connections at equipment and instruments.

Instruments will be mounted and supported in accordance with Bechtel standard drawings.

Appendix C

ENVIRONMENTAL POLLUTION CONSIDERATIONS

The alkali scrubbing process is based on the recycling of essentially all process water and does not, under normal operating conditions, produce liquid discharges. Under emergency and scheduled shutdowns, however, significant amounts of liquids of objectionable composition can be discharged to the environment. The following discussions pertain to such discharges and also to leachate from the solids disposal pot.

C. 1 GENERAL

The most important effect of the introduction of calcium and magnesium ions into natural waters is an increase in the hardness. High levels of hardness are undesirable in waters used for domestic and most industrial purposes since they result in higher cleansing costs and various undesirable effects on industrial processes. Some recommended levels are: domestic water supply – less than 250 mg/l, with less than 100 mg/l desirable; boiler feed – 2 to 80 mg/l, depending on pressure; food processing – 10 to 250 mg/l; pulp and paper making – 100 to 200 mg/l; textile manufacture – 0 to 50 mg/l; and steel manufacture – 50 mg/l. Irrigation water use is seldom limited by the hardness, and the effects on fish and other aquatic life are slight. High levels of hardness may actually be beneficial to the fish population in that their sensitivity to metallic and other toxic compounds in general is lower in hard waters than in soft.

For domestic water supplies, sulfates should not exceed 500 mg/l, and should preferably be lower than 250 mg/l, since laxative effects become discernible at the higher levels. High levels of sulfate are in general undersirable for industrial uses. Maximum recommended levels for some selected industries are as follows: dairy industry — 60 mg/l; sugar making — 20 mg/l; and textile manufacture — 100 mg/l. For irrigation uses, less than 200 mg/l is considered good, and more than 500 mg/l is generally considered hazardous. Of U. S. waters supporting good populations of game fish, 5 percent contain less than 11 mg/l of sulfates, 50 percent less than 32 mg/l, and 95 percent less than 90 mg/l.

Calcium sulfate (gypsum) is soluble to the extent of about 2500 mg/l in cold water. The taste threshold is about 250 mg/l, with no harmful effects at that level. Higher levels are undesirable for domestic and industrial uses except for the brewing industry, where it is recommended to levels of 500 mg/l, depending on the type of beer produced. For irrigation uses, calcium sulfate has beneficial effects. Fish and other aquatic organisms are unaffected by high concentrations of calcium sulfate.

Magnesium sulfate (Epsom salt) is freely soluble in water. The taste threshold as well as the lower level of purgative effects is about 400 mg/l. Only the brewing industry has been concerned with high levels of magnesium sulfate. Irrigation uses and the protection of fish and other aquatic life do not pose particular limitations.

Sulfite is detrimental to natural waters basically as an oxygen-consuming compound. The oxidation from sulfite to sulfate takes place at a high rate, utilizing the dissolved oxygen of the water. Thus, a significant reduction in dissolved oxygen levels may take place. The main problem thus created is the effect on fish and other aquatic life. While different species have varying requirements, depending on water temperature and other chemical and physical characteristics, 5 to 6 mg/l of dissolved oxygen is generally considered to be a minimum for healthy conditions.

High suspended solids concentrations may be a characteristic of the initial leachate water and other occasional discharges. This can result in an increase in the receiving water turbidity, which could be objectionable both for municipal and industrial water supplies.

C. 2 SPECIFIC CONSIDERATIONS REGARDING THE TEST FACILITY

No liquids are discharged to the environment under normal operating conditions. For emergencies and occasional clean-up, the clarifier with its pipeline and hold tank system may have to be drained. The volume of water would be about 250,000 gallons and the flow rate 175 gpm if discharged over a period of one day. By allowing the water to settle in the clarifier for a brief period of time preceding the discharge, a suspended solids content of 200 mg/l or less can be achieved. The dissolved solids are primarily calcium and magnesium sulfates and may range from 4000 mg/l when limestone is injected, to 400,000 mg/l with dolomite injection.

The receiving water body in this case is the St. Clair River, which belongs to the interstate waters under the jurisdiction of the Michigan Water Resources Commission. The standards which must be complied with are indicated in the publication "Summary of Water Quality Standards for Designated Use Areas in Michigan Interstate Waters," State of Michigan, Water Resources Commission, Department of Natural Resources, November 1968. The following quotes are taken from this document:

MICHIGAN WATER RESOURCES COMMISSION
DESIGNATED USE AREAS - ST. CLAIR RIVER

"Based on their existing uses and reasonable future uses, the waters of the St. Clair River, Lake St. Clair, Detroit River and Lake Erie will be protected as described below.

1. All the above named waters will be protected for Water Supply — Domestic, except that portion of the Detroit River from Point Hennepin to the mouth. The individual parameters shall be measured at the point of water withdrawal.

2. All the above named waters will be protected for Water Supply — Industrial. The individual para meters shall be measured at the point of water withdrawal.

3. All the above named waters, except at the mouths of tributaries, in the immediate vicinity of enclosed harbor areas and in the immediate vicinity of waste water treatment plant outfalls will be protected for Recreation — Total Body Contact; except for conditions relating to natural causes.

4. All the above named waters will be protected for Fish, Wildlife and Other Aquatic Life — Warm Water Sport Fish.

5. All the above named waters will be protected for Commercial Navigation in the designated navigation channels as maintained by the U. S. Corps of Engineers.

Where the waters are classified under more than one designated water use, it is intended that the most restrictive individual standard of the designated water uses shall be adhered to.

In areas adjacent to outfalls, standards for the designated water use, or uses shall apply after admixture of waste effluents with the public waters but in no instance shall the mixing zone act as a barrier to fish migration or interfere unreasonably with the designated water use or uses for the area. The Water Resources Commission must have discretion in determining the extent of the mixing zone. In general, the Water Resources Commission encourages the use of outfall structures which minimize the extent of the mixing zone."

The most restrictive standards are those for domestic water supplies and, for some parameters, for the protection of fish, wildlife, and other aquatic life. These standards are listed in Table C-1. It should also be noted that the effluent from the power plant ash pond has been shown to significantly affect the quality of water at water intakes at Marin City and particularly at East China Township, which is only a few hundred yards downstream from the plant.

For the experimental facility, a schedule of intended discharges and anticipated concentrations of major constituents, as indicated previously, must be presented to the Commission by the Detroit Edison Company. The Commission will then rule on the necessity of treatment or impose other restrictions. The Commission has been contacted informally with regard to the discharges from the experimental facility and indicated that specific treatment requirements appeared unlikely.

Table C-1

WATER QUALITY STANDARDS FOR ST. CLAIR RIVER

Parameter	Most Restrictive Designated Use Area	Quality Standards
1. Coliform Group (organisms/ 100 ml or MPN)	Water Supply—Domestic (such as drinking, culinary, and food processing)	The monthly geometric average shall not exceed 5,000, nor shall 20 percent of the samples examined exceed 5,000, nor shall 5 percent of the samples exceed 20,000.
2. Dissolved Oxygen (mg/1)	Fish, Wildlife and Other Organisms (such as growth and propagation)	At the average low river flow of 7-day duration expected to occur once in 10 years, the following DO values shall be maintained for: Intolerant fish — cold water species: Not less than 6 at any time. Intolerant fish — warm water species: Average daily DO not less than 5, nor shall any single value be less than 4. Tolerant fish — warm water species: Average daily DO not less 4, nor shall any single value be less than 3. At greater flows, the DO shall be in excess of these values.
3. Suspended, Colloidal, and Settleable Materials	Water Supply — Domestic (such as drinking, culinary, and food processing)	No objectionable unnatural turbidity, color, or deposits shall be present in quantities sufficient to interfere with the designated use.
4. Residues (debris and material of unnatural origin and oils)	Water Supply — Domestic (such as drinking, culinary, and food processing)	Floating Solids: None of unnatural origin. Residues: No evidence of such material except of natural origin. No visible film of oil, gasoline, or related materials. No globules of grease.
5. Toxic and Deleterious Substances	Water Supply — Domestic (such as drinking, culinary, and food processing)	Conform to current USPHS Drinking Water Standards except: Cyanide: Normally not detectable with a maximum upper limit of 0.05 mg/1 Phenol: Limitation as defined under Taste and Odor Producing Substances (8).
	Fish, Wildlife, and Other Organisms (such as growth and propagation)	Not to exceed 1/10 of the 96-hour median tolerance limit obtained from continuous-flow bio-assays where the dilution water and toxicant are continuously renewed, except that other application factors may be used in specific cases when justified on the basis of available evidence and approved by the appropriate agency.

Table C-1 (Cont)

WATER QUALITY STANDARDS FOR ST. CLAIR RIVER

<table>
<tr><th>Parameter</th><th>Most Restrictive Designated Use Area</th><th>Quality Standards</th></tr>
<tr><td>6. Total Dissolved Solids (mg/l)</td><td>Water Supply — Domestic (such as drinking, culinary, and food processing)</td><td>For Great Lakes and Connecting Waters: Total Dissolved Solids: The maximum shall not exceed 200. Chlorides: The monthly average shall not exceed 50. A monthly average of 10 is a desirable limit where existing conditions are less than 10. For Inland Waters: Total Dissolved Solids: Shall not exceed 500 as a monthly average, nor exceed 750 at any time. Chlorides: The monthly average shall not exceed 125.</td></tr>
<tr><td>7. Nutrients (phosphorus, ammonia, nitrates, and sugars)</td><td>Water Supply — Domestic (such as drinking, culinary, and food processing)</td><td>Nutrients originating from industrial, municipal, or domestic animal source shall be limited to the extent necessary to prevent (1) adverse effects on water treatment processes or (2) the stimulation of growths of algae, weeds, and slimes which are or may become injurious to the designated use.</td></tr>
<tr><td>8. Taste and Odor Producing Substances</td><td>Water Supply — Domestic (such as drinking, culinary, and food processing)</td><td>Concentrations of substances of unnatural origin shall be less than those which are or may become injurious to the designated use. Monthly average phenol concentration shall be less than 0.002 mg/l-maximum concentration limited to 0.005 mg/l for a single sample.</td></tr>
<tr><td>9. Temperature (°F)</td><td>Fish, Wildlife, and Other Organisms (such as growth and propagation)</td><td><table>
<tr><th></th><th>Ambient</th><th>Max. Incr.</th><th>Max. Limit</th></tr>
<tr><td>Intolerant fish-cold water species</td><td>32° nat. max.</td><td>10°</td><td>70°</td></tr>
<tr><td>Intolerant fish-warm water spcs</td><td>32-35°
36°-nat. max.</td><td>15°
10°</td><td>
85°</td></tr>
<tr><td>Tolerant fish-warm wat. spcs</td><td>32-59°
60°-nat. max.</td><td>15°
10°</td><td>
87°</td></tr>
</table>
For the Great Lakes and Connecting Waters: No heat load shall occur in sufficient quantity to create conditions (1) which are or may become injurious to domestic, commercial, industrial, agricultural, recreational, or other uses which are being or may be made of such waters; or (2) which are or may become injurious to livestock, wild animals, birds, fish, or aquatic life or the growth or propagation thereof.</td></tr>
</table>

Table C-1 (Cont)

WATER QUALITY STANDARDS FOR ST. CLAIR RIVER

Parameter	Most Restrictive Designated Use Area	Quality Standards
10. Hydrogen Ion (pH)	Water Supply — (such as drinking, culinary, and food processing)	Shall be maintained between 6. 5 and 8. 8. with a maximum artificially induced variation of 0. 5 unit within this range. Changes in the pH of natural waters outside these values must be toward neutrality (7. 0).
11. Radioactive Materials	Water Supply — (such as drinking, culinary, and food processing)	An upper limit of 1000 picocuries/liter of gross beta activity (in absence of alpha emitters and Strontium-90). If this limit is exceeded, the specific radionuclides present must be identified by complete analysis in order to establish the fact that the concentration of nuclides will not produce exposures above the recommended limits established by the Federal Radiation Council.

D INSTRUMENT ENGINEERING
STANDARDS

INSTRUMENT ENGINEERING STANDARDS

FIRST LETTER		SECOND & SUCCEEDIN												
MEASURED VARIABLE	SYMBOL FOR MEASURED VARIABLES	DISPLAY DEVICES							CONTROLLING DEV				
		INDICATING	RECORDING	INTEGRATING INDICATOR (See Note 5)	SCAN (See Note 7)	ALARM (See Note 12)			INDICATING	RECORDING	BLIND	CONTROL VALVE	S ACT VA
						LOW	HIGH	LOW HIGH					
Typical Symbol	( )	( ) I	( ) R	( ) Q I	( ) J ( )	( ) AL	( ) AH	( ) AHL	( ) IC	( ) RC	( ) C	( ) V	(
Analysis (See Note 1)	A	AI	AR		AJ ( )	AAL	AAHL	AAHL	AIC	ARC	AC	AV	
Burner Flame	B	BI	BR		BJ ( )	BAL					BC	BV	
Conductivity	C	CI	CR		CJ ( )	CAL	CAH	CAHL	CIC	CRC		CV	
Density	D	DI	DR		DJ ( )	DAL	DAH	DAHL	DIC	DRC		DV	
Voltage (EMF)	E	EI	ER		EJ ( )	EAL	EAH	EAHL	EIC	ERC	EC		
Flow (See Note 10)	F	FI	FR	FQI	FJ ( )	FAL	FAH	FAHL	FIC	FRC	FC	FV	FC
Flow Ratio	FF	FFI	FFR		FFJ ( )				FFIC	FFRC	FFC	FFV	
Gaging (Dimensional)	G	GI	GR		GJ ( )	GAL	GAH	GAHL	GIC	GRC	GC	GV	
Hand	H								HIC		HC	HV	HC
Current	I	II	IR	IQI	IJ ( )	IAL	IAH	IAHL	IIC	IRC	IC		
Power	J	JI	JR	JQI	JJ ( )	JAL	JAH	JAHL	JIC	JRC	JC		
Time	K	KI	KR	KQI	KJ ( )	KAL	KAH	KAHL	KIC	KRC	KC		
Level	L	LI	LR		LJ ( )	LAL	LAH	LAHL	LIC	LRC	LC	LV	LC
Moisture	M	MI	MR		MJ ( )	MAL	MAH	MAHL	MIC	MRC	MC	MV	
Users Choice (See Note 2)	N												
Torque	O	OI	OR		OJ ( )	OAL	OAH	OAHL	OIC	ORC	OC	OV	(See
Pressure	P	PI	PR		PJ ( )	PAL	PAH	PAHL	PIC	PRC	PC	PV	PC
Pressure Differential	PD	PDI	PDR			PDAL	PDAH	PDAHL	PDIC	PDRC	PDC	PDV	PDC
Quantity or Event	Q	QI	QR	QQI	QJ ( )	QAL	QAH	QAHL	QIC	QRC	QC	QV	
Radiation	R	RI	RR	RQI	RJ ( )	RAL	RAH	RAHL	RIC	RRC	RC		
Speed or Frequency	S	SI	SR	SQI	SJ ( )	SAL	SAH	SAHL	SIC	SRC	SC		
Temperature	T	TI	TR		TJ ( )	TAL	TAH	TAHL	TIC	TRC	TC	TV	TC
Temperature Differential	TD	TDI	TDR			TDAL	TDAH	TDAHL	TDIC	TDRC	TDC	TDV	TDC
Multi-Variable	U	UI	UR		UJ ( )	UAL	UAH	UAHL	UIC	URC	UC	UV	
Viscosity	V	VI	VR		VJ ( )	VAL	VAH	VAHL	VIC	VRC	VC	VV	
Weight	W	WI	WR	WQI	WJ ( )	WAL	WAH	WAHL	WIC	WRC	WC	WV	
Unclassified (See Note 4)	X	XI	XR		XJ ( )	XAL	XAH	XAHL	XIC	XRC	XC	XV	
User's Choice (See Note 2)	Y												
Position	Z	ZI	ZR		ZJ ( )	ZAL	ZAH	ZAHL	ZIC	ZRC	ZC		

NOTES

(1) "A" is used for all analytical variables: For example: O_2, H_2O, CO_2, pH, octane improvement, chromatograph analyzing one or more streams for one or more compounds, boiling point, freezing point, combustibles etc. The chemical formula recognized symbol (such as pH) or a description denoting the function of the analyzer should be noted on the P&ID outside the instrument symbol.

(2) A user's choice letter is intended to cover a meaning that would be used repetitively in a particular project. When used, the letter may have one meaning as a first letter and another meaning as a succeeding letter. The meanings need be defined only once in a legend, or otherwise for that project. For example, the letter "N" may be defined as turbidity as a first letter and television monitor as a second letter. "BN" would be a burner flame television monitor.

(3) The equation or description denoting the function of the relay "Y" should be shown on the P&ID. For example: A+B+C+K, LP selector, volume booster.

(4) "X" is used to represent any "special" variables and may be defined as required. For example: Mass flow recorders which receive a signal from a multiplying relay which combines the product of density and flow. This item is not to be confused with "U" multi-variable symbol.

(5) When "Q" is used as a second or succeeding letter it denotes an integrating modifier. For example: "FQI" is an indicating flow integrator (or totalizer). Note that the integrating function shall be shown with separate identification: For example: FQI/FRS or FR/FQIS.

(6) Startup and shutdown devices are usually blind, but may be indicating or recording. If so, add "I" or "R" after measured variable. For example: FIS, TRS. If the switch performs an on-off control function, replace "S" by "C". For example: "FS" becomes "FC". Switch functions shall be further modified by "L" for low and "H" for high.

(7) The designation "AJ ( )" may denote a scanning analyzer indicator, recorder, transmitter, etc., by using the designation AJI, AJR, AJT, etc., respectively.

(8) "TW" denotes an empty thermowell. "TE" denotes a thermowell with thermocouple or resistance bulb and head suitable for use with a secondary instrument.

(9) Pressure relief valves and rupture disks shall be identified as "PSV" and "PSE" respectively.

(10) "FO" is used to designate a restriction orifice.

(11) For devices other than control valves, such as hydraulic couplings, variable speed drives, etc.

(12) High-high alarms will be designated "( ) AHH" and low-low alarms "( ) ALL". For example: LAHH denotes "high-high level alarm".

GENERAL NOTES:

(A) All instrument identifications are based u

(B) Where special designation is required, pl
letter "L".

A

SECOND & SUCCEEDING LETTERS												
	CONTROLLING DEVICES						SENSING DEVICES					
ATING	RECORDING	BLIND	CONTROL VALVE	SELF ACTUATED VALVE	FINAL CONTROL ELEMENT (See Note 11)	SWITCH (See Note 6)	PRIMARY ELEMENT	BLIND TRANSMITTER	INDICATING TRANSMITTER	LOCAL OBSERVATION GLASS	TEST CONNECTION	(See Note 3) RELAY OR CONVERTER (BLIND)
IC	( )RC	( )C	( )V	( )CV	( )Z	( )S( )	( )E	( )T	( )IT	( )G	( )P	( )Y
C	ARC	AC	AV		AZ	AS ( )	AE	AT	AIT		AP	AY
		BC	BV			BS ( )	BE	BT		BG	BP	BY
C	CRC		CV		CZ	CS ( )	CE	CT	CIT		CP	CY
C	DRC		DV		DZ	DS ( )	DE	DT	DIT		DP	DY
C	ERC	EC			EZ	ES ( )	EE	ET	EIT			EY
C	FRC	FC	FV	FCV	FZ	FS ( )	FE	FT	FIT	FG	FP	FY
C	FFRC	FFC	FFV		FFZ							
C	GRC	GC	GV		GZ	GS ( )	GE	GT	GIT			
C		HC	HV	HCV	HZ	HS ( )						
C	IRC	IC			IZ	IS ( )	IE	IT	IIT			IY
C	JRC	JC			JZ	JS ( )	JE	JT	JIT			JY
C	KRC	KC			KZ	KS ( )		KT	KIT			KY
C	LRC	LC	LV	LCV	LZ	LS ( )	LE	LT	LIT	LG	LP	LY
C	MRC	MC	MV		MZ	MS ( )	ME	MT	MIT		MP	MY
C	ORC	OC	OV	(See Note 8)	OZ	OS ( )	OE	OT				OY
C	PRC	PC	PV	PCV	PZ	PS ( )	PE	PT	PIT		PP	PY
C	PDRC	PDC	PDV	PDCV	PDZ	PDS ( )		PDT	PDIT			
C	QRC	QC	QV		QZ	QS ( )		QT	QIT			QY
C	RRC	RC			RZ	RS ( )	RE	RT	RIT		RP	RY
C	SRC	SC			SZ	SS ( )		ST	SIT			SY
C	TRC	TC	TV	TCV	TZ	TS ( )	TE	TT	TIT		TW	TY
C	TDRC	TDC	TDV	TDCV	TDZ	TDS ( )	(See Note 8)				(See Note 8)	
C	URC	UC	UV		UZ	US ( )						UY
C	VRC	VC	VV		VZ	VS ( )	VE	VT	VIT			VY
C	WRC	WC	WV		WZ	WS ( )	WE	WT	WIT			WY
C	XRC	XC	XV		XZ	XS ( )	XE	XT	XIT			XY
												YY
C	ZRC	ZC			ZZ	ZS ( )	ZE	ZT	ZIT			ZY

GENERAL NOTES:

(A) All instrument identifications are based upon ISA standard "S5.1 - 1967". For further details refer to ISA standard.

(B) Where special designation is required, pilot lights shall be identified with the particular variable letter, followed by second letter "L".

INSTRUMENT ENGINEERING STANDARD

INSTRUMENT IDENTIFICATION

6955 Appendix D-1

B

INSTALLATION SCHEDULE (SEE NOTE 4)		INSTRUMENTS ARE PLACED IN A GROUP DEPENDENT UPON THEIR FUNCTION	ALL INSTRUMENTS WITHIN A GROUP AND IN THE SAME PLANT SHALL BE NUMBERED CONSECUTIVELY STARTING WITH NO. 1, 201 OR 501 AS INDICATED IN THE EXAMPLES BELOW, AND PREFIXED WITH THE PLANT NUMBER.
SERIAL NO.	TITLE	TYPICAL GROUPS	TYPICAL EXAMPLES (ASSUME PLANT NO. 4)
1	ALARMS	FAL, FAH, LAL, LAH, PAH, JA, ETC.	4FAL-1 4PAH-2 4JA -3 4LAL-4
2	ANALYSIS INSTRUMENTS	ARC, AIC, AI, AR	4AR-1 4AIC-2 4ARC-3
3	FLOW INSTRUMENTS	FRC, FIC, FFRC, FCL, FR, FI, FE	4FRC-1 4FR-2 4FIC-3
4	RESTRICTION ORIFICES AND SIGHT GLASSES	FO, FG	4FO-501 4FO-502 4FG-503 4FG-504
5	LEVEL INSTRUMENTS	LRC, LIC, LCV, LCL, LCH, LR, LC, LI	4LRC-1 4LIC-2 4LCL-3 4LR-4
6	LEVEL GAGES	LG	4LG-1 4LG-2 4LG-3
7	MISCELLANEOUS INSTRUMENTS	SI, SR, SRC, WIC, WRC, CRC, CI, RI, HIC, HC, HCV, DRC, DIC, BC, Y, ER, EIC, KIC, KR, VI, VRC, TQR, THL, etc	4SI-1 4SRC-2 4RI-3 4HIC-4 4SI-5
8	PRESSURE INSTRUMENTS	PRC, PIC, PDI, PDIC, PDR PCV, PCH, PI, PR	4PRC-1 4PDL-2 4PCH-3 4PR-4
9	PRESSURE GAGES	PI	4PI-501 4PI-502
10	PRESSURE RELIEF VALVES PRESSURE RELIEF ELEMENTS (RUPTURE DISK)	PSV, PSE	4PSV-1 4PSE-2 4PSV-3 4PSE-4
11	TEMPERATURE INSTRUMENTS	TRC, TIC, TDIC, TDRC TCV, TCL, TI, TR, TC	4TIC-1 4TCV-2 4TI-3 4TR-4
12	MULTIPOINT TJR ELEMENTS	TJR	4TJR-501 4TJR-502 4TJR-503
13	MULTIPOINT TI SYSTEM ELEMENTS	TI	4TI-501 4TI-502 4TI-503
14	TEMPERATURE GAGES, WELLS AND ELEMENTS	TI, TE, TW	4TI-201 4TW-202 4TI-203 4TE-204 4TE-205

A

TRUMENTS WITHIN A GROUP AND SAME PLANT SHALL BE NUMBERED UTIVELY STARTING WITH NO. 1, 201 OR 501 CATED IN THE EXAMPLES BELOW, EFIXED WITH THE PLANT NUMBER.	INSTRUMENTS SHALL BE GROUPED ACCORDING TO MEASURED VARIABLE ON INSTALLATION SCHEDULE
. EXAMPLES (ASSUME PLANT NO. 4)	FORM NUMBER
4FAL-1 4PAH-2 4JA -3 4LAL-4	252 B
4AR-1 4AIC-2 4ARC-3	252 A
4FRC-1 4FR-2 4FIC-3	252 A
4FO-501 4FO-502 4FG-503 4FG-504	252 B
4LRC-1 4LIC-2 4LCL-3 4LR-4	252 A
4LG-1 4LG-2 4LG-3	252 B
4SI-1 4SRC-2 4RI-3 4HIC-4 4SI-5	252 A
4PRC-1 4PDL-2 4PCH-3 4PR-4	252 A
4PI-501 4PI-502	252B
4PSV-1 4PSE-2 4PSV-3 4PSE-4	252B
4TIC-1 4TCV-2 4TI-3 4TR-4	252 A
4TJR-501 4TJR-502 4TJR-503	252 B
4TI-501 4TI-502 4TI-503	252 B
4TI-201 4TW-202 4TI-203 4TE-204 4TE-205	252 B

GENERAL NOTES

1. All instruments listed on Data Sheets shall be prefixed with the number of the plant with which they are associated.

2. On Instrument Installation Schedules the plant prefix shall be shown at the top of the column reading: "Instrument No." and need not be repeated for each instrument.

3. The plant prefix shall not be included on P&ID's and Instrument Location Plans. However, a note shall be included on these drawings stating the following: "All instruments on this drawing are prefixed by Plant No. ___ except as noted."

4. A separate Instrument Installation Schedule sheet shall be made for each group of instruments, titled as indicated and numbered as follows: Job No. 9999-IS, Plant No. 4J, Serial No. 1.
   Note: If several sheets are required for a single category (Flow Instruments, for example), they shall be numbered as follows: 9999-IS-4J-3, Sheet 1 of 3, 9999-IS-4J-3, Sheet 2 of 3, etc.

5. All components in the same control loop will carry the same number except for alarms.

6. Instruments furnished with package units (such as compressors) shall be correctly identified, symbolized and numbered in accordance with this standard, J-G-0101, and J-G-0103, and/or J-G-0104.

7. Instrument Identification shall be per Bechtel Standard J-G-0101.

8. Instrument Symbols shall be per Bechtel Standard J-G-0103 and/or J-G-0104.

No	DATE	REVISIONS	BY	CHK'D	ENG'R			CLIENT

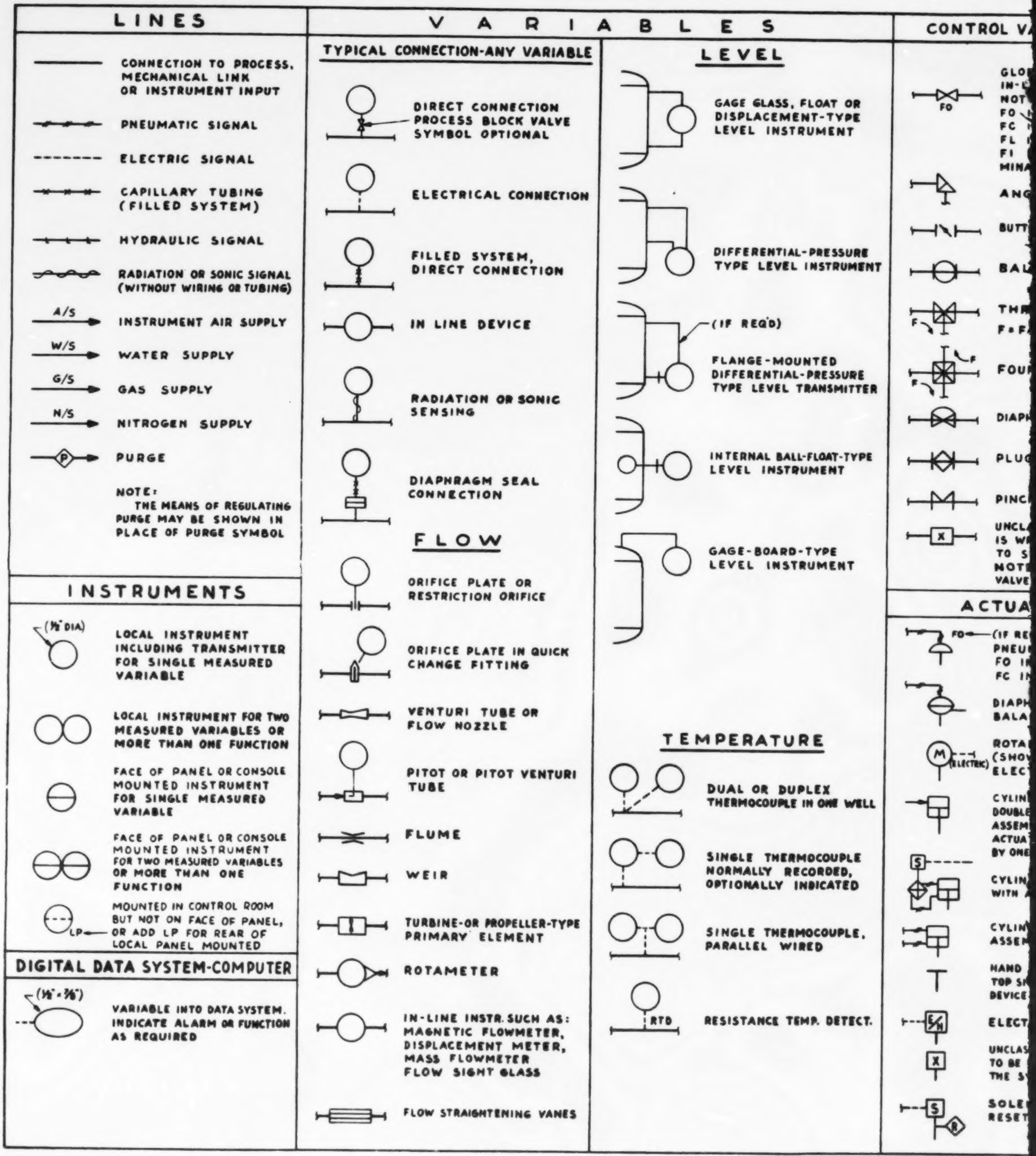
INSTRUMENT ENGINEERING STANDARD

NUMBERING OF INSTRUMENTS
AND INSTALLATION SCHEDULES

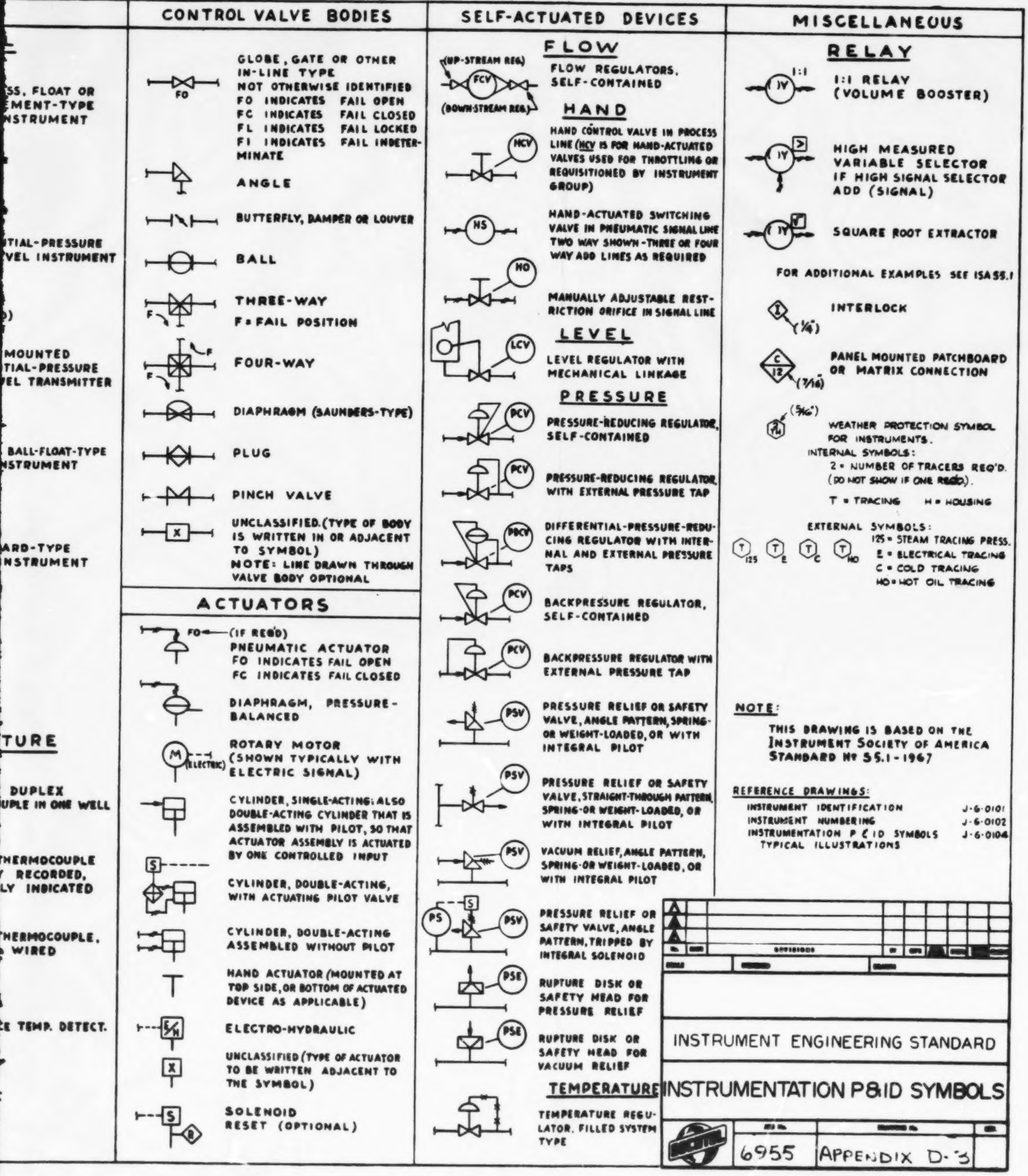
BECHTEL

JOB No.	DRAWING No.	REV.
6955	APPENDIX D-2	

B


LINES
CONNECTION TO PROCESS, MECHANICAL LINK OR INSTRUMENT INPUT
PNEUMATIC SIGNAL
ELECTRIC SIGNAL
CAPILLARY TUBING (FILLED SYSTEM)
HYDRAULIC SIGNAL
RADIATION OR SONIC SIGNAL (WITHOUT WIRING OR TUBING)
A/S
INSTRUMENT AIR SUPPLY
W/S
WATER SUPPLY
G/S
GAS SUPPLY
N/S
NITROGEN SUPPLY
P
PURGE
NOTE: THE MEANS OF REGULATING PURGE MAY BE SHOWN IN PLACE OF PURGE SYMBOL
INSTRUMENTS
(½" DIA)
LOCAL INSTRUMENT INCLUDING TRANSMITTER FOR SINGLE MEASURED VARIABLE
LOCAL INSTRUMENT FOR TWO MEASURED VARIABLES OR MORE THAN ONE FUNCTION
FACE OF PANEL OR CONSOLE MOUNTED INSTRUMENT FOR SINGLE MEASURED VARIABLE
FACE OF PANEL OR CONSOLE MOUNTED INSTRUMENT FOR TWO MEASURED VARIABLES OR MORE THAN ONE FUNCTION
MOUNTED IN CONTROL ROOM BUT NOT ON FACE OF PANEL, OR ADD LP FOR REAR OF LOCAL PANEL MOUNTED
LP
DIGITAL DATA SYSTEM-COMPUTER
(½" · ⅜")
VARIABLE INTO DATA SYSTEM. INDICATE ALARM OR FUNCTION AS REQUIRED
VARIABLES
TYPICAL CONNECTION-ANY VARIABLE
DIRECT CONNECTION PROCESS BLOCK VALVE SYMBOL OPTIONAL
ELECTRICAL CONNECTION
FILLED SYSTEM, DIRECT CONNECTION
IN LINE DEVICE
RADIATION OR SONIC SENSING
DIAPHRAGM SEAL CONNECTION
FLOW
ORIFICE PLATE OR RESTRICTION ORIFICE
ORIFICE PLATE IN QUICK CHANGE FITTING
VENTURI TUBE OR FLOW NOZZLE
PITOT OR PITOT VENTURI TUBE
FLUME
WEIR
TURBINE-OR PROPELLER-TYPE PRIMARY ELEMENT
ROTAMETER
IN-LINE INSTR. SUCH AS: MAGNETIC FLOWMETER, DISPLACEMENT METER, MASS FLOWMETER FLOW SIGHT GLASS
FLOW STRAIGHTENING VANES
LEVEL
GAGE GLASS, FLOAT OR DISPLACEMENT-TYPE LEVEL INSTRUMENT
DIFFERENTIAL-PRESSURE TYPE LEVEL INSTRUMENT
(IF REQ'D)
FLANGE-MOUNTED DIFFERENTIAL-PRESSURE TYPE LEVEL TRANSMITTER
INTERNAL BALL-FLOAT-TYPE LEVEL INSTRUMENT
GAGE-BOARD-TYPE LEVEL INSTRUMENT
TEMPERATURE
DUAL OR DUPLEX THERMOCOUPLE IN ONE WELL
SINGLE THERMOCOUPLE NORMALLY RECORDED, OPTIONALLY INDICATED
SINGLE THERMOCOUPLE, PARALLEL WIRED
RTD
RESISTANCE TEMP. DETECT.
CONTROL V
FO
GLO
IN-
NOT
FO
FC
FL
FI
MINA
ANG
BUTT
BAL
F
THR
F = F
F
F
FOU
DIAPH
PLUG
PINC
X
UNCLA
IS W
TO S
NOTE
VALVE
ACTUA
FO
(IF RE
PNEU
FO I
FC I
DIAPH
BALA
M
(ELECTRIC)
ROTA
(SHOV
ELEC
CYLIN
DOUBLE
ASSEM
ACTUA
BY ONE
S
CYLIN
WITH
CYLIN
ASSEM
HAND
TOP S
DEVICE
E/H
ELECT
X
UNCLAS
TO BE
THE S
S
R
SOLE
RESET

A



SS, FLOAT OR
EMENT-TYPE
NSTRUMENT

TIAL-PRESSURE
VEL INSTRUMENT

)

MOUNTED
TIAL-PRESSURE
VEL TRANSMITTER

BALL-FLOAT-TYPE
NSTRUMENT

ARD-TYPE
NSTRUMENT

TURE

DUPLEX
UPLE IN ONE WELL

THERMOCOUPLE
RECORDED,
LY INDICATED

THERMOCOUPLE,
WIRED

E TEMP. DETECT.

CONTROL VALVE BODIES

GLOBE, GATE OR OTHER IN-LINE TYPE NOT OTHERWISE IDENTIFIED
FO INDICATES FAIL OPEN
FC INDICATES FAIL CLOSED
FL INDICATES FAIL LOCKED
FI INDICATES FAIL INDETERMINATE

ANGLE

BUTTERFLY, DAMPER OR LOUVER

BALL

THREE-WAY
F = FAIL POSITION

FOUR-WAY

DIAPHRAGM (SAUNDERS-TYPE)

PLUG

PINCH VALVE

UNCLASSIFIED. (TYPE OF BODY IS WRITTEN IN OR ADJACENT TO SYMBOL)
NOTE: LINE DRAWN THROUGH VALVE BODY OPTIONAL

ACTUATORS

(IF REQ'D)
PNEUMATIC ACTUATOR
FO INDICATES FAIL OPEN
FC INDICATES FAIL CLOSED

DIAPHRAGM, PRESSURE-BALANCED

ROTARY MOTOR (SHOWN TYPICALLY WITH ELECTRIC SIGNAL)

CYLINDER, SINGLE-ACTING; ALSO DOUBLE-ACTING CYLINDER THAT IS ASSEMBLED WITH PILOT, SO THAT ACTUATOR ASSEMBLY IS ACTUATED BY ONE CONTROLLED INPUT

CYLINDER, DOUBLE-ACTING, WITH ACTUATING PILOT VALVE

CYLINDER, DOUBLE-ACTING ASSEMBLED WITHOUT PILOT

HAND ACTUATOR (MOUNTED AT TOP SIDE, OR BOTTOM OF ACTUATED DEVICE AS APPLICABLE)

ELECTRO-HYDRAULIC

UNCLASSIFIED (TYPE OF ACTUATOR TO BE WRITTEN ADJACENT TO THE SYMBOL)

SOLENOID
RESET (OPTIONAL)

SELF-ACTUATED DEVICES

FLOW

FLOW REGULATORS, SELF-CONTAINED

HAND

HAND CONTROL VALVE IN PROCESS LINE (HCV IS FOR HAND-ACTUATED VALVES USED FOR THROTTLING OR REQUISITIONED BY INSTRUMENT GROUP)

HAND-ACTUATED SWITCHING VALVE IN PNEUMATIC SIGNAL LINE TWO WAY SHOWN - THREE OR FOUR WAY ADD LINES AS REQUIRED

MANUALLY ADJUSTABLE RESTRICTION ORIFICE IN SIGNAL LINE

LEVEL

LEVEL REGULATOR WITH MECHANICAL LINKAGE

PRESSURE

PRESSURE-REDUCING REGULATOR, SELF-CONTAINED

PRESSURE-REDUCING REGULATOR, WITH EXTERNAL PRESSURE TAP

DIFFERENTIAL-PRESSURE-REDUCING REGULATOR WITH INTERNAL AND EXTERNAL PRESSURE TAPS

BACKPRESSURE REGULATOR, SELF-CONTAINED

BACKPRESSURE REGULATOR WITH EXTERNAL PRESSURE TAP

PRESSURE RELIEF OR SAFETY VALVE, ANGLE PATTERN, SPRING- OR WEIGHT-LOADED, OR WITH INTEGRAL PILOT

PRESSURE RELIEF OR SAFETY VALVE, STRAIGHT-THROUGH PATTERN, SPRING-OR WEIGHT-LOADED, OR WITH INTEGRAL PILOT

VACUUM RELIEF, ANGLE PATTERN, SPRING-OR WEIGHT-LOADED, OR WITH INTEGRAL PILOT

PRESSURE RELIEF OR SAFETY VALVE, ANGLE PATTERN, TRIPPED BY INTEGRAL SOLENOID

RUPTURE DISK OR SAFETY HEAD FOR PRESSURE RELIEF

RUPTURE DISK OR SAFETY HEAD FOR VACUUM RELIEF

TEMPERATURE

TEMPERATURE REGULATOR, FILLED SYSTEM TYPE

MISCELLANEOUS

RELAY

1:1 RELAY (VOLUME BOOSTER)

HIGH MEASURED VARIABLE SELECTOR IF HIGH SIGNAL SELECTOR ADD (SIGNAL)

SQUARE ROOT EXTRACTOR

FOR ADDITIONAL EXAMPLES SEE ISA S5.1

INTERLOCK

PANEL MOUNTED PATCHBOARD OR MATRIX CONNECTION

WEATHER PROTECTION SYMBOL FOR INSTRUMENTS.
INTERNAL SYMBOLS:
2 = NUMBER OF TRACERS REQ'D. (DO NOT SHOW IF ONE REQ'D).
T = TRACING H = HOUSING

EXTERNAL SYMBOLS:
125 = STEAM TRACING PRESS.
E = ELECTRICAL TRACING
C = COLD TRACING
HO = HOT OIL TRACING

NOTE:

THIS DRAWING IS BASED ON THE INSTRUMENT SOCIETY OF AMERICA STANDARD Nº S5.1-1967

REFERENCE DRAWINGS:

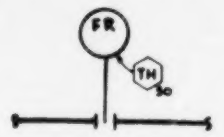
INSTRUMENT IDENTIFICATION	J-6-0101
INSTRUMENT NUMBERING	J-6-0102
INSTRUMENTATION P & ID SYMBOLS TYPICAL ILLUSTRATIONS	J-6-0104

INSTRUMENT ENGINEERING STANDARD

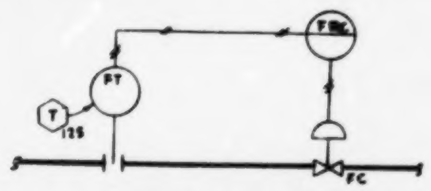
INSTRUMENTATION P&ID SYMBOLS

6955 APPENDIX D-3

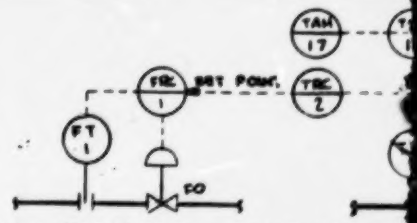
B



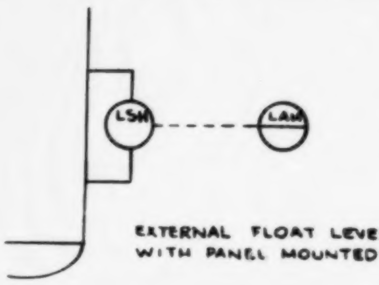
LOCAL FLOW RECORDER
(DIFFERENTIAL PRESSURE TYPE)
WITH 50# STEAM TRACING AND HOUSED


FRC
FT
T
125
FC

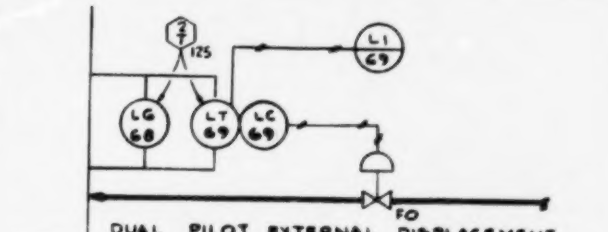
FLOW RECORDING CONTROLLER
PANEL MOUNTED
WITH 125# STEAM TRACING


TAH
17
FRC
1
SET POINT
TRC
2
FT
1
FO

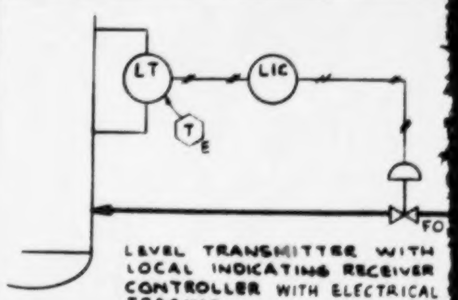
FLOW RECORDING CONTROLLER RECEIVING
POINT SIGNAL FROM PANEL MOUNTED T
CONTROLLER WITH HIGH TEMPERATURE
AND ALARM



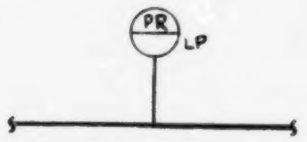
EXTERNAL FLOAT LEVEL SWITCH
WITH PANEL MOUNTED ALARM


2
T
125
LI
69
LG
68
LT
69
LC
69
FO

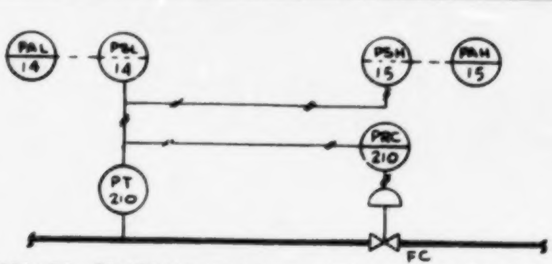
DUAL PILOT EXTERNAL DISPLACEMENT
LEVEL CONTROLLER WITH PANEL MOUNTED
INDICATOR AND LOCAL LEVEL GAUGE GLASS
WITH TWO 125# STEAM TRACERS



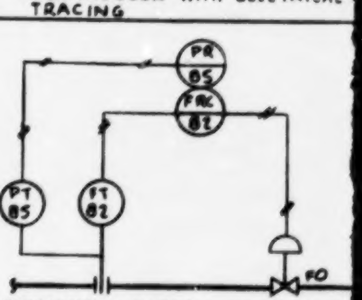
LEVEL TRANSMITTER WITH
LOCAL INDICATING RECEIVER
CONTROLLER WITH ELECTRICAL
TRACING



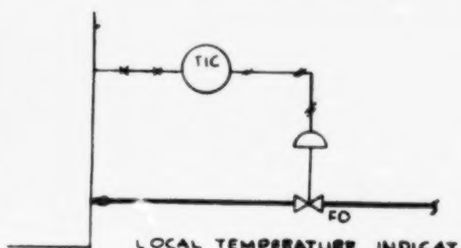
PRESSURE RECORDER
DIRECT CONNECTED ON LOCAL PANEL


PAL
14
PSL
14
PSH
15
PAH
15
PRC
210
PT
210
FC

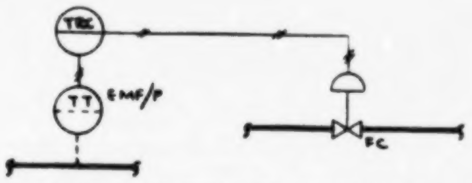
PRESSURE RECORDING CONTROL LOOP WITH HIGH-LOW
MONITOR SWITCHES AND ALARMS


PR
85
FRC
82
PT
85
FT
82
FO

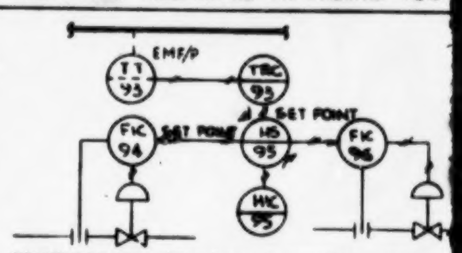
FLOW RECORDING CONTROL LOOP WITH
PRESSURE RECORDING ON SECOND PEN



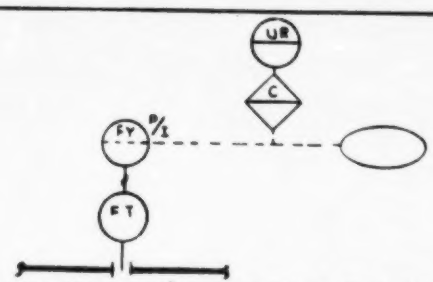
LOCAL TEMPERATURE INDICATING
CONTROLLER (FILLED SYSTEM SENSOR)


TRC
TT
EMF/P
FC

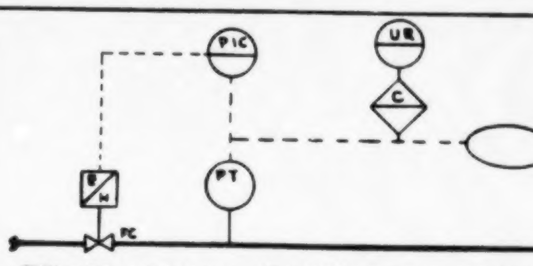
PANEL MOUNTED TEMPERATURE RECORDING AND PANEL
MOUNTED EMF/AIR TRANSMITTER


TT
93
EMF/P
TRC
93
SET POINT
FIC
94
SET POINT
HS
95
FIC
96
HIC
95

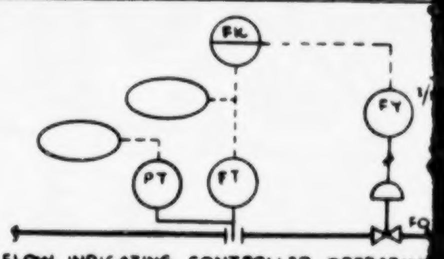
TEMPERATURE RECORDING CONTROLLER AC
SET POINT OF MANUALLY SELECTED FLOW
CONTROLLERS, WITH OPTIONAL MANUAL
OF FLOW CONTROL SET POINT.



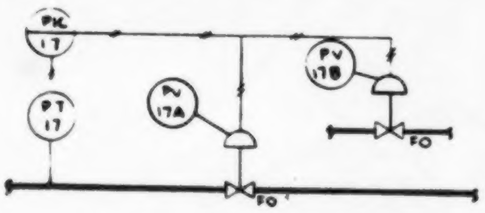
FLOW MEASUREMENT TO COMPUTER VIA PANEL MOUNTED
AIR TO CURRENT CONVERTER & JACK FOR TREND RECORDER


PIC
UR
C
E
H
PT
FC

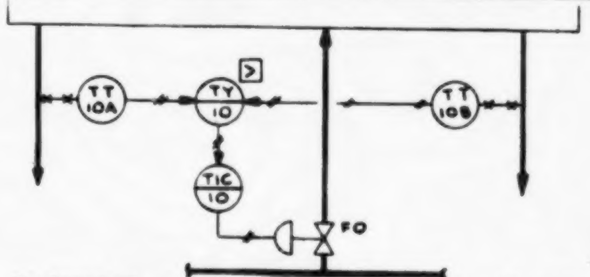
PRESSURE INDICATING CONTROLLER, WITH MEASUREMENT
TO COMPUTER AND JACK FOR TREND RECORDER, ACTUATING
ELECTRO-HYDRAULIC CONTROL VALVE.


FIC
FY
PT
FT
FO

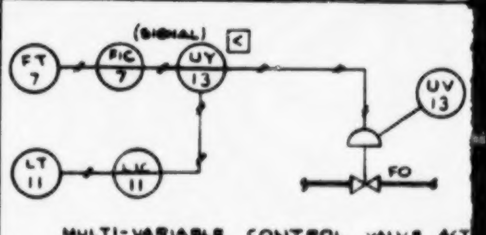
FLOW INDICATING CONTROLLER OPERATIN
ELECTRO-PNEUMATIC CONTROL VALVE,
COMPUTER INPUTS FOR FLOW & PRESSURE


PIC
17
PT
17
PV
17A
PV
17B
FO

SINGLE PRESSURE CONTROLLER FOR
SPLIT-RANGE SERVICE

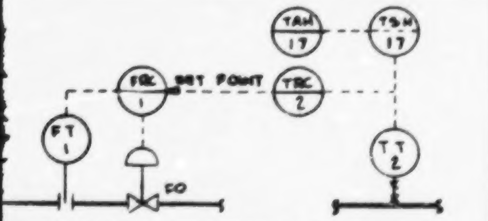

TT
10A
TY
10
>
TT
10B
TIC
10
FO

TEMPERATURE CONTROL LOOP WITH DUAL SENSORS
AND HIGH SIGNAL SELECTOR RELAY

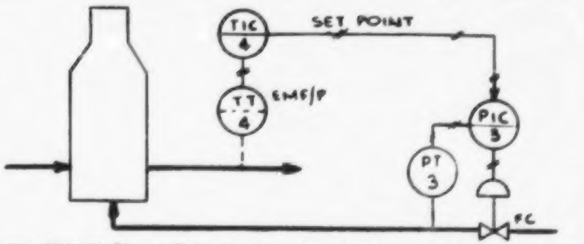

(SIGNAL)
<
FT
7
FIC
7
UY
13
UV
13
LT
11
LIC
11
FO

MULTI-VARIABLE CONTROL VALVE ACT
BY EITHER FLOW OR LEVEL CONTR
THRU A LOW SIGNAL SELECTOR RE

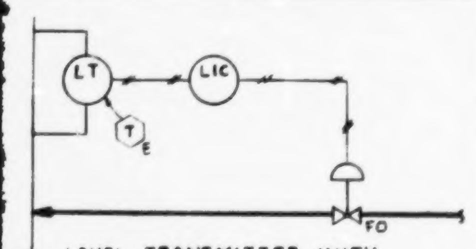
A


TAH 17
TSH 17
FRC 1
SET POINT
TRC 2
FT 1
TT 2
FO

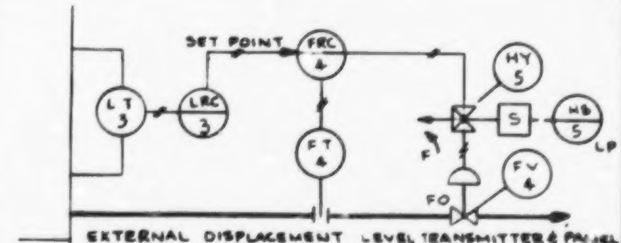
W RECORDING CONTROLLER RECEIVING SET
T SIGNAL FROM PANEL MOUNTED TEMPERATURE
TROLLER WITH HIGH TEMPERATURE SWITCH
D ALARM


TIC 4
SET POINT
TT 4
EMF/P
PIC 3
PT 3
FC

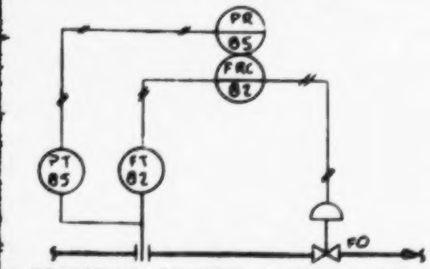
TEMPERATURE INDICATING CONTROLLER PROVIDING SET POINT TO INDICATING PRESSURE CONTROLLER



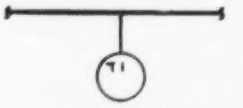
LEVEL TRANSMITTER WITH LOCAL INDICATING RECEIVER CONTROLLER WITH ELECTRICAL TRACING


SET POINT
FRC 4
HY 5
LT 3
LRC 3
S
HS 5
LP
FT 4
F
FO
FV 4

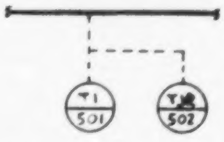
EXTERNAL DISPLACEMENT LEVEL TRANSMITTER & PANEL MOUNTED RECORDING CONTROLLER ACTUATING SET POINT OF FLOW RECORDING CONTROL LOOP WITH REMOTE ACTUATED SOLENOID VALVE


PR 85
FRC 82
PT 85
FT 82
FO

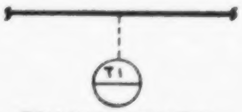
W RECORDING CONTROL LOOP WITH
SSURE RECORDING ON SECOND PEN



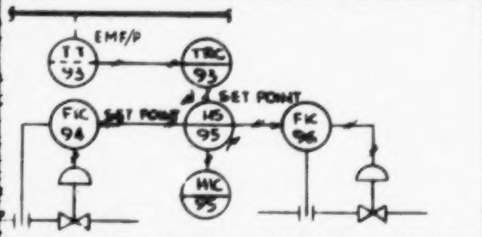
THERMOMETER


TI 501
TJR 502

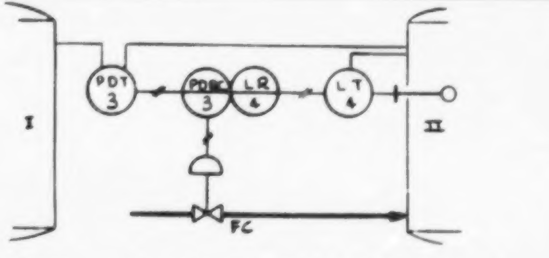
SINGLE THERMOCOUPLE PARALLEL WIRED TO MULTI-POINT TEMPERATURE INDICATOR AND MULTI-POINT SCANNING TEMPERATURE RECORDER



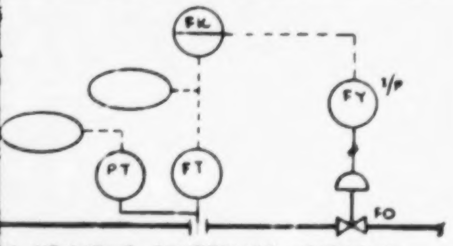
REMOTE MOUNTED TEMPERATURE INDICATOR


EMF/P
TT 93
TRC 93
SET POINT
FIC 94
SET POINT
HS 95
FIC 96
HIC 95

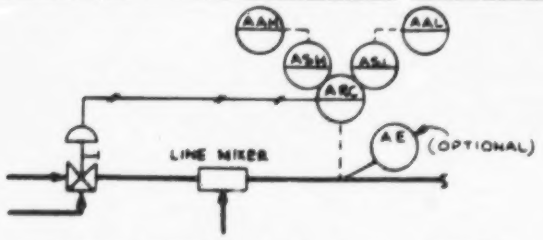
ERATURE RECORDING CONTROLLER ACTUATING
POINT OF MANUALLY SELECTED FLOW INDICATING
TROLLERS, WITH OPTIONAL MANUAL LOADING
FLOW CONTROL SET POINT.


I
PDT 3
PDRC 3
LR 4
LT 4
II
FC

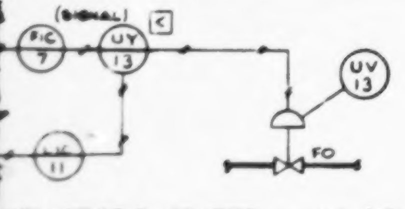
DIFFERENTIAL PRESSURE LOOP WITH LEVEL RECORDING ON SECOND PEN


FIC
FY
I/P
PT
FT
FO

W INDICATING CONTROLLER OPERATING
CTRO-PNEUMATIC CONTROL VALVE,
PUTER INPUTS FOR FLOW & PRESSURE


AAH
AAL
ASH
ASL
ARC
AE
(OPTIONAL)
LINE MIXER

ANALYZER CONTROL LOOP WITH INTEGRAL ALARM SWITCHES IN RECORDER CONTROLLER


(SIGNAL)
<
FIC 7
UY 13
UV 13
LIC 11
FO

LTI-VARIABLE CONTROL VALVE ACTUATED
Y EITHER FLOW OR LEVEL CONTROL
HRU A LOW SIGNAL SELECTOR RELAY

NOTES

1. THESE EXAMPLES ARE PRESENTED TO ILLUSTRATE THE USE OF THE BASIC SYMBOLS SHOWN ON STANDARD DRAWING NO. J-6-0103
2. NUMBERS SHOWN ARE TYPICAL ONLY
3. TYPICAL ILLUSTRATIONS ARE BASED ON ISA STANDARD S5.1 - 1967

REFERENCE DRAWINGS

INSTRUMENT IDENTIFICATION	J-6-0101
INSTRUMENT NUMBERING	J-6-0102
INSTRUMENT P&ID SYMBOLS	J-6-0103

REVISIONS

INSTRUMENT ENGINEERING STANDARD

INSTRUMENTATION P&ID SYMBOLS
TYPICAL ILLUSTRATIONS

BECHTEL

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B

INSTRUMENT ITEM	CALIBRATION REQUIREMENT	TEST EQUIPMENT AND/OR SPECIAL TOOLS REQUIREMENTS
ALARMS:		
ANNUNCIATOR SYSTEMS	CHECK OPERATING SEQUENCE, CHECK LIGHTS.	SIMPSON METER, POWER SOURCE
(FOR ACTUATING DEVICES - SEE "SWITCHES"		
UNDER EACH PRIMARY MEASURING FUNCTION)		
CONTROL PANELS:		
SEMIGRAPHIC, GRAPHIC, NON-GRAPHIC,	VISUAL INSPECTION VS. APPROVED DRAWINGS	
LOCAL, & RACKS	UNLESS PANEL WAS SHOP INSPECTED BEFORE SHIPPING	
	CALIBRATE PANEL INSTRUMENTS IN ACCORDANCE	
	WITH SPECIFIC ITEM REQUIREMENTS	SEE SPECIFIC ITEM REQUIREMENTS
ELECTRONICS:		
RECORDERS	REFCAL	MFR'S TEST EQUIPMENT, SIMPSON METER
INDICATORS	DITTO	DITTO
RECORDING CONTROLLERS	REFCAL, CHECK CONTROL ACTION, SET PRELIMINARY MODES ⑩	DITTO
INDICATING CONTROLLERS	DITTO ⑩	DITTO
RELAYS	REFCAL, CHECK RELAY FUNCTIONS, SET PER DATA SHEET	DITTO
ELECTRONIC/PNEUMATIC CONVERTERS	REFCAL, CHECK ZERO & SPAN	DITTO, MANOMETER, REGULATED AIR SUPPLY
INDICATORS (FIELD)	NO CALIBRATION	—
POWER SUPPLIES (CONSTANT VOLTAGE, ETC.)	DITTO	—
TEST EQUIPMENT	DITTO	—
FLOW:		
TRANSMITTERS-DIFF. PRESS. DIAPH. OR BELLOWS (N)	REFCAL	MANOMETER, REGULATED AIR SUPPLY, PRESSURE SOURCE
TRANSMITTERS-DIFF. PRESS. DIAPH. OR BELLOWS (E)	DITTO	MANOMETER, PRESSURE SOURCE, POWER SUPPLY, SIMPSON METER
INDIC., RECORD., CONTROL., METER-MERCURY	FILL WITH MERCURY, REFCAL, CHECK CONTROL ACTION SET PRELIMINARY MODES ⑩	MANOMETER, PRESSURE SOURCE
INDIC., RECORD., CONTROL., METER-BELLOWS	DITTO ⑩	DITTO
ROTAMETERS-TRANS. OR CONT. (N)	NO PRIMARY CALIBRATION, MOVE FLOAT LINKAGE TO REFCAL ⑩⑫	MANOMETER, REGULATED AIR SUPPLY
ROTAMETERS-TRANS. OR CONT. (E)	DITTO ⑩⑫	SIMPSON METER, POWER SOURCE
ROTAMETERS-INDICATING	NO CALIBRATION ⑫	—
POSITIVE DISPLACEMENT TYPE METERS	DITTO	—
ORIFICE PLATES	CHECK BORE FOR DIMENSIONAL ACCURACY	VERNIER OR MICROMETER CALIPERS
ORIFICE RUNS	NO CALIBRATION - FOR VENDOR CALIBRATED RUNS SEE ⑫	—
VENTURIS	DITTO ⑫	—
FLOW TUBES	DITTO ⑫	—
PITOT TUBES	DITTO ⑫	—
PITOT VENTURIS	DITTO ⑫	—
SWITCHES	NO CALIBRATION, CHECK ACTUATION, SET PER DATA SHEET	SIMPSON METER, POWER SOURCE
ELECTROMAGNETIC	NO CALIBRATION ⑫	REQUEST VENDOR SERVICE.
PROPELLER	DITTO ⑫	DITTO
TURBINE	DITTO ⑫	DITTO
MASS METER	DITTO ⑫	DITTO
RESTRICTION ORIFICE	CHECK BORE FOR DIMENSIONAL ACCURACY	DRILL GAGE OR VERNIER OR MICROMETER CALIPERS
LEVEL:		
DISPLACEMENT - TRANSMITTERS (N)	REFCAL W/H_2O, ADJUST SPECIFIC GRAVITY	MANOMETER, REGULATED AIR SUPPLY, WATER SOURCE
DISPLACEMENT - TRANSMITTERS (E)	DITTO	SIMPSON METER, POWER SOURCE, WATER SOURCE
DISPLACEMENT - CONTROLLERS (OR DUAL)	DITTO - CHECK CONTROL ACTION, SET PRELIMINARY CONTRL MODE ⑩	MANOMETER, REGULATED AIR SUPPLY, WATER SOURCE
DIFFERENTIAL - TRANSMITTERS (N)	REFCAL, SET SUPPRESSION OR ELEVATION	MANOMETER, REGULATED AIR SUPPLY, PRESSURE SOURCE
DIFFERENTIAL - TRANSMITTERS (E)	DITTO	SIMPSON METER, POWER SOURCE, PRESSURE SOURCE
GAGE GLASSES	NO CALIBRATION	—
SWITCHES - FLOAT TYPE (N)	OPERATE W/H_2O, CHECK ACTUATION	REGULATED AIR SUPPLY, WATER SOURCE
SWITCHES - FLOAT TYPE (E)	DITTO	SIMPSON METER, POWER SOURCE
SWITCHES - CAPACITANCE TYPE	NO CALIBRATION - CHECK ACTUATION	SAMPLE OF FLUID, SIMPSON METER, POWER SOURCE
INDICATORS, SWITCHES - RADIOACTIVE TYPE	CALIBRATION BY INSTRUMENT ENGINEER ONLY	—
TANK GAGES	REFCAL TO HAND GAGE AFTER LIQUID IS IN TANK - ONE POINT ONLY	REQUEST VENDOR SERVICE
BUBBLER TYPE	REFCAL	MANOMETER, REGULATED AIR SUPPLY
PNEUMATICS:		
RECORDERS	REFCAL	MANOMETER, REGULATED AIR SUPPLY
INDICATORS	DITTO	DITTO
RECORDER CONTROLLERS	REFCAL - CHECK CONTROL ACTION - SET PRELIM. MODE ⑩	DITTO
INDICATING CONTROLLERS	DITTO ⑩	DITTO
BLIND CONTROLLERS	DITTO ⑩	DITTO
RELAYS	REFCAL - CHECK RELAY FUNCTIONS, SET PER DATA SHEET	DITTO

INSTRUMENT ITEM	CA
VOLUME BOOSTERS	REFCA
SUB-PANELS	
PRESSURE:	
TRANSMITTERS (N)	REFCA
TRANSMITTERS (E)	
TRANSMITTERS - ABSOLUTE PRESS. OR DRAFT (N)	
TRANSMITTERS - ABSOLUTE PRESS. OR DRAFT (E)	
TRANSMITTERS - DIFFERENTIAL PRESS. (N)	
TRANSMITTERS - DIFFERENTIAL PRESS. (E)	
INDIC., RECORD., CONTROL (N)	REFCAL
BLIND CONTROLLERS (N)	
SWITCHES	REFCA
GAGES	NO CA
DRAFT GAGES - MANOMETER TYPE	NO CAL
ANALYZERS:	
OXYGEN	CALIBRA
MOISTURE	EACH I
THERMAL CONDUCTIVITY	AGAINS
INFRA RED	SERVIC
CHROMATOGRAPH	OF ALL
END POINT	IF SOU
pH	CONTA
DENSITY	
OTHER ANALYTICAL INSTRUMENTS	
SAMPLING SYSTEMS FOR ABOVE	
SYSTEMS:	
DATA HANDLING	CALIBRA
COMPUTERS	
REMOTE TANK LEVEL & TEMP.	
CONTROL SYSTEMS - I.E. BOILER,	COMPON
WATER TRTG, COMPRESSOR, ETC.	REQUIR
	CHECKO
TEMPERATURE:	
TRANSMITTERS - BULB TYPE (N)	REFCAL
TRANSDUCERS - EMF/AIR (E/N)	
TRANSDUCERS - EMF/ELECTRONIC (E)	
INDIC., RECORD., CONTROL - BULB TYPE	REFCAL-
MULTIPOINT POTENTIOMETER - RECORDERS	REFCAL.
MULTIPOINT POTENTIOMETER - INDICATORS	
MULTIPOINT POTENTIOMETER - CONSOLES	
DIAL THERMOMETERS - BI - METALLIC	NO CAL
DIAL THERMOMETERS - BULB TYPE	
THERMOCOUPLE ASSEMBLIES	NO CALI
THERMOWELLS	NO CALI
SWITCHES (BULB TYPE)	REFCAL
SWITCHES (THERMOCOUPLE TYPE)	
INDICATORS (MILLIVOLTMETER TYPE)	REFCAL
VALVES (AND OPERATORS):	
CONTROL VALVES - PNEUMATIC DIAPHRAGM	CHECK
CONTROL VALVES - PNEUMATIC PISTON	
CONTROL VALVES - ELECTRO HYDRAULIC	CHECK AC
CONTROL VALVES - ELECTRIC	
CONTROL VALVES - ELECTRIC MOTOR OPERATED	
CONTROL VALVES - AIR MOTOR OPERATED	CHECK AC
SOLENOID VALVES	CHECK
HAND CONTROL VALVES	CHECK
BUTTERFLY VALVES	CHECK
SLIDE VALVES	CHECK A
POSITIONERS - PNEUMATIC	CHECK
POSITIONERS - ELECTRO/PNEUMATIC	
PRESSURE CONTROL VALVES MEASUREMENT ACTUATED	CHECK
TEMPERATURE CONTROL VALVES (MEASUREMENT ACTUATED)	

A

INSTRUMENT ITEM	CALIBRATION REQUIREMENT	TEST EQUIPMENT AND/OR SPECIAL TOOLS REQUIREMENTS
VOLUME BOOSTERS	REFCAL - CHECK RELAY FUNCTION	MANOMETER, REGULATED AIR SUPPLY
SUB-PANELS	DITTO	DITTO
PRESSURE:		
TRANSMITTERS (N)	REFCAL	MANOMETER, REGULATED AIR SUPPLY, PRESSURE SOURCE
TRANSMITTERS (E)	DITTO	SIMPSON METER, PRESSURE SOURCE
TRANSMITTERS-ABSOLUTE PRESS. OR DRAFT (N)	DITTO	MANOMETER, REGULATED AIR SUPPLY, VACUUM SOURCE
TRANSMITTERS-ABSOLUTE PRESS. OR DRAFT (E)	DITTO	MANOMETER, POWER SOURCE, SIMPSON METER, VACUUM SOURCE
TRANSMITTERS-DIFFERENTIAL PRESS. (N)	DITTO	PRECISION GAGE, REGULATED AIR SUPPLY, PRESSURE SOURCE
TRANSMITTERS-DIFFERENTIAL PRESS. (E)	DITTO	PRECISION GAGE, POWER SOURCE, SIMPSON METER, PRESSURE SOURCE
INDIC., RECORD., CONTROL (N)	REFCAL - CHECK CONTROL ACTION - SET PREL. MODE ⑩	MANOMETER, REGULATED AIR SUPPLY, PRESSURE SOURCE
BLIND CONTROLLERS (N)	DITTO ⑩	DITTO
SWITCHES	REFCAL-CHECK ACTUATION, SET PER DATA SHEET	SIMPSON METER, PRESSURE SOURCE
GAGES	NO CALIBRATION	–
DRAFT GAGES-MANOMETER TYPE	NO CALIBRATION - FILL & ZERO	LIQUID - PER DATA SHEET
ANALYZERS:		
OXYGEN	CALIBRATION BY INSTRUMENT ENGINEER ONLY	REQUEST VENDOR SERVICE
MOISTURE	EACH INSTRUMENT MUST BE FULLY CALIBRATED	
THERMAL CONDUCTIVITY	AGAINST KNOWN SAMPLE STANDARD REQUEST VENDOR	
INFRA RED	SERVICE. CHECK EARLY IN JOB FOR AVAILABILITY	
CHROMATOGRAPH	OF ALL SAMPLES; CARRIER GAS, PURGES, ETC.	
END POINT	IF SOURCE OF SAMPLES ETC IS NOT CLEAR,	
pH	CONTACT PROJECT ENGINEER.	
DENSITY		
OTHER ANALYTICAL INSTRUMENTS		
SAMPLING SYSTEMS FOR ABOVE		
SYSTEMS:		
DATA HANDLING	CALIBRATION BY INSTRUMENT & ELECTRICAL ENGINEER ONLY	REQUEST VENDOR SERVICE
COMPUTERS	DITTO	DITTO
REMOTE TANK LEVEL & TEMP.	DITTO	DITTO
CONTROL SYSTEMS - I.E. BOILER, WATER TRTG, COMPRESSOR, ETC.	COMPONENT CALIBRATION PER SPECIFIC ITEM REQUIREMENTS. FINAL SYSTEM OPERATION CHECKOUT BY INSTRUMENT ENGINEER.	DITTO
TEMPERATURE:		
TRANSMITTERS - BULB TYPE (N)	REFCAL	MANOMETER, REGULATED AIR SUPPLY, PRECISION THERMOMETER, TEMPERATURE BATH.
TRANSDUCERS-EMF/AIR (E/N)	DITTO	MANOMETER, REGULATED AIR SUPPLY, PORTABLE POTENTIOMETER, POWER SOURCE
TRANSDUCERS-EMF/ELECTRONIC (E)	DITTO	SIMPSON METER, PORTABLE POTENTIOMETER, POWER SOURCE
INDIC., RECORD., CONTROL-BULB TYPE	REFCAL-CHECK CONTROL ACTION - SET PRELIM. MODE ⑦	MANOMETER, REGULATED AIR SUPPLY, PRECISION THERMOMETER, TEMPERATURE BATH, POWER SOURCE
MULTIPOINT POTENTIOMETER - RECORDERS	REFCAL	PORTABLE POTENTIOMETER, POWER SOURCE
MULTIPOINT POTENTIOMETER - INDICATORS	DITTO	DITTO
MULTIPOINT POTENTIOMETER - CONSOLES	DITTO	DITTO
DIAL THERMOMETERS - BI - METALLIC	NO CALIBRATION	–
DIAL THERMOMETERS - BULB TYPE	DITTO	–
THERMOCOUPLE ASSEMBLIES	NO CALIBRATION - CHECK WIRE & POLARITY	PORTABLE POTENTIOMETER
THERMOWELLS	NO CALIBRATION	–
SWITCHES (BULB TYPE)	REFCAL - CHECK ACTUATION - SET PER DATA SHEET	SIMPSON METER, TEMPERATURE BATH, PRECISION THERMOMETER
SWITCHES (THERMOCOUPLE TYPE)	DITTO	DITTO, OR MANUFACTURERS TEST EQUIPMENT
INDICATORS (MILLIVOLTMETER TYPE)	REFCAL	PORTABLE POTENTIOMETER
VALVES (AND OPERATORS):		
CONTROL VALVES - PNEUMATIC DIAPHRAGM	CHECK ACTION & STROKE	REGULATED AIR SUPPLY
CONTROL VALVES - PNEUMATIC PISTON	DITTO	DITTO
CONTROL VALVES ELECTRO HYDRAULIC	CHECK ACTION & STROKE - BY INSTRUMENT & EL. ENGINEER ONLY	SIMPSON METER POWER SOURCE
CONTROL VALVES - ELECTRIC	DITTO	DITTO
CONTROL VALVES - ELECTRIC MOTOR OPERATED	DITTO	DITTO
CONTROL VALVES - AIR MOTOR OPERATED	CHECK ACTION & STROKE - BY INSTRUMENT ENGINEER ONLY	MANOMETER, AIR SUPPLY
SOLENOID VALVES	CHECK ACTION	POWER SOURCE
HAND CONTROL VALVES	CHECK POSITION INDICATOR	–
BUTTERFLY VALVES	CHECK ACTION & STROKE	REGULATED AIR SUPPLY OR POWER SOURCE
SLIDE VALVES	CHECK ACTION & STROKE - BY INSTRUMENT ENGINEER ONLY	DITTO
POSITIONERS - PNEUMATIC	CHECK WITH VALVE, ADJUST RANGE PER DATA SHEET	MANOMETER, REGULATED AIR SUPPLY
POSITIONERS - ELECTRO/PNEUMATIC	DITTO	SIMPSON METER OR MANUFACTURERS TEST EQUIP., POWER SOURCE
PRESSURE CONTROL VALVES MEASUREMENT ACTUATED	CHECK ACTION & STROKE	MANOMETER, PRESSURE SOURCE
TEMPERATURE CONTROL VALVES (MEASUREMENT ACTUATED)	DITTO	TEMPERATURE BATH, PRECISION THERMOMETER

NOTES

① THIS GUIDE MAY BE SUPPLEMENTED BY MANUFACTURERS' INSTRUMENT MANUALS. IF SUCH MANUALS ARE NOT AVAILABLE IN FIELD ADVISE PROJECT ENGINEER IMMEDIATELY.

② USE THIS CALIBRATION GUIDE AS REQUIREMENT REFERENCE IN ALL CASES UNLESS SPECIFICALLY EXCEPTED BY SUPERSEDING SPECIFICATION.

③ THE TERM "REFCAL" USED ON THIS DRAWING IS DEFINED "CALIBRATE AGAINST ACCEPTABLE STANDARD REFERENCE SIGNAL, INPUT AND/OR OUTPUT" THIS WILL BE DONE WITH THE INSTRUMENT "IN PLACE" WHEREVER POSSIBLE.

④ "CALIBRATE" IS DEFINED "TO DEMONSTRATE THE ABILITY OF AN INSTRUMENT TO AGREE WITH A STANDARD REFERENCE QUANTITY (GENERALLY TEST AT 3 POINTS IN RANGE). LIMITED TO MANUFACTURERS PUBLISHED PERFORMANCE SPECIFICATION ON ACCURACY."

⑤ THE TERM "CHECK" AS USED ON THIS DRAWING IS DEFINED "CHECK AND SET OR RESET AS REQUIRED".

⑥ (N) = PNEUMATIC ; (E) = ELECTRONIC.

⑦ GUIDE TO PRELIMINARY CONTROL MODES:

APPLICATION	PROP. BAND %	RESET RATE REP./MIN	DERIV. TIME MIN.
FLOW	150	0.1	0
PRESSURE (LIQUID)	50	0	0
PRESSURE (VAPOR)	100	0	0
DIFF. PRESS. (LIQUID)	50	0.1	0
DIFF. PRESS. (VAPOR)	100	0.1	0
LEVEL	100	0	0
TEMPERATURE	100	0.3	0.5
ANALYZER	100	0	0

⑧ FOR DIMENSIONAL TOLERANCES ON ORIFICE PLATES, REFER TO BECHTEL STANDARD DWG. J-F-9001 & 9002.

⑨ WHERE MANOMETER IS SPECIFIED ON THIS DRAWING, A PRECISION CALIBRATED PRESSURE GAUGE MAY BE SUBSTITUTED.

⑩ ALL CONTROLLERS WHICH HAVE VALVE ACTION INDICATORS (OPEN-CLOSE) SHALL BE CHECKED FOR PROPER MARKING IN ACCORDANCE WITH CONTROL ACTION.

⑪ REFER TO LATEST REVISION OF INSTRUMENT DATA SHEET FOR ALARM & CUTOFF SWITCH SETTINGS, SPECIFIC GRAVITY OF PROCESS LIQUIDS, TYPE OF FILLING FLUIDS, ETC.

⑫ VENDOR WILL FURNISH CALIBRATION CURVES, CHARTS, FACTORS, ETC. FOR SOME ITEMS, I.E. ROTAMETERS, VENTURIS, MASS FLOW METERS, ETC.

INSTRUMENT ENGINEERING STANDARD

INSTRUMENT CALIBRATION GUIDE

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B

Appendix E

BIBLIOGRAPHY

The references listed in this appendix were consulted during the performance of this study. Those not specifically referred to in this text are headed "Uncited References." Those referred to in Sections 5 and 6 are headed "Cited References."

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